Partnership on Transparency
in the Paris Agreement

Harnessing Transparency for Industry Decarbonisation

Good Practices in Greenhouse Gas Inventory Compilation for the Industry Sector

Deutsche Gesellschaft
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Table of Contents

About the Partnership on Transparency in the Paris Agreement

In May 2010, Germany, South Africa and South Korea launched the Partnership on Transparency in the Paris Agreement (formerly: International Partnership on Mitigation and MRV) in the context of the Petersberg Climate Dialogue with the aim of promoting ambitious climate action through practical exchange. With the Paris Agreement entering into force in 2016, the path has now been paved for the Partnership to focus on implementing the Agreement and particularly on the Enhanced Transparency Framework. Over 100 countries, more than half of which are developing countries, have taken part in the Partnership's various activities to date. The Partnership has no formal character and is open to new countries. Currently, the secretariat of PATPA is hosted by the GIZ Support Project for the Implementation of the Paris Agreement (SPA).

Find more information on the partnership here:
www.transparency-partnership.net

List of Tables

List of Figures

Abbreviations

AFOLU	Agriculture, Forestry, and Other Land Use
AWACS	Airborne Warning and Control System
BF	Blast Furnace
BOF	Basic Oxygen Furnace
BTR	Biennial Transparency Reports
BUR	Biennial Update Reports
C_2F_6	Hexafluoroethane
C40	Cities Climate Leadership Group
CaO	Calcium Oxide
CBAM	Carbon Border Adjustment Mechanism
CCF	Carbon Content Factor
CF_4	Carbon Tetrafluoride
CH_4	Methane
CKD	Cement Kiln Dust
CN	Common Nomenclature
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COF	Carbon Oxidation Factor
CSI	Cement Sustainability Initiative
CCUS	Carbon Capture, Utilisation, and Storage
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EF(s)	Emission Factor(s)
EFDB	Emission Factor Database
ETF	Enhanced Transparency Framework
ETS	Emission Trading Systems
EU	European Union
F-gases	Fluorinated Greenhouse Gases
GHG	Greenhouse Gas(es)

GPCs	Global Protocol for the Community-Scale Greenhouse Gas Emission Inventories
H_2-DRI	Hydrogen-Based Direct Reduced Iron
HFCs	Hydrofluorocarbons
HNO_3	Nitric Acid
HTFs	Heat Transfer Fluids
IABr	Instituto Aço Brasil
ICLEI	Local Governments for Sustainability
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
ISIC	International Standard Industrial Classification
kg	Kilogram
LKD	Lime Kiln Dust
LPG	Liquefied Petroleum Gas
MgO	Magnesium oxide
MoU	Memorandum of Understanding
MRV	Monitoring, Reporting, and Verification
NCV	Net Calorific Value
NC	National Communications
NDC	National Determined Contribution
NF_3	Nitrogen Trifluoride
NH_3	Ammonia
NID	National Inventory Document
NMVOCs	Non-Methane Volatile Organic Compounds
N_2O	Nitrous Oxide
NOx	Nitrogen Oxides
ODSs	Ozone-Depleting Substances
ODU	Oxidation During Use
OECD	Organisation for Economic Co-operation and Development
OHFs	Open Hearth Furnaces

PATPA	Partnership on Transparency in the Paris Agreement
PFCs	Perfluorocarbons
PV	Photovoltaics
QA/QC	Quality Assurance / Quality Control
SF_6	Sulphur Hexafluoride
SO_2	Sulphur Dioxide
t	tonne
TJ	Terajoule
TurkStat	Turkish Statistical Institute
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compounds
WRI	World Resource Institute

Glossary

Enhanced Transparency Framework (ETF)	Paris Agreement's unified transparency framework requiring BTRs with national GHG inventory information, with flexibility for developing countries that need it.
Biennial Transparency Report (BTR)	Report to be submitted every two years by all developed and developing countries (with least developed countries and small island developing states submitting BTRs at their discretion) under the ETF of the Paris Agreement covering national GHG inventory information, information on NDC progress of implementation, adaptation, and support provided/received.
National Inventory Report (NIR)	Report documenting information on national GHG emissions and removals by sinks, which can be submitted either as a separated document (NID) or as part of the BTR.
National Inventory Document (NID)	A part of the NIR to GHG inventory information.
Common Reporting Tables (CRT)	A standardised set of electronic tables used by countries to report their national GHG emissions and removals.
IPCC source category notation	Structured codes for reporting sectors and subsectors (e.g., Energy 1, Fuel Combustion 1.A, Energy Industries 1.A.1, Manufacturing Industries and Construction 1.A.2).
International Standard Industrial Classification (ISIC)	Classification used to align industrial subcategories within 1.A.2 for reporting and energy statistics.
Industrial Processes and Product Use (IPPU)	Sector covering process-related emissions from production/use of industrial goods.
Key category analysis	Identification of categories and gases that most influence the level and/or trend of national GHG emissions to prioritize higher Tiers, data collection, and QA/QC.

Tier (Tier 1/2/3) A level of complexity in methodologies used to estimate GHG emissions.

Emission factor (EF) Coefficient used to convert activity data to GHG emissions expressing the carbon content of fossil fuels or raw materials/feedstocks (e.g., kg gas per TJ fuel).

Activity data (AD) Quantitative measure of the activity that generates GHG emissions (e.g., fuel consumption), used with EFs to estimate emissions.

Emission Factor Database (EFDB) IPCC database of documented EFs and parameters that may suit national circumstances; correct application remains the compiler's responsibility.

Time-series consistency Using consistent methods, activity data, and EFs across years with recalculation as needed to maintain a consistent annual series.

Uncertainty assessment Quantitative and qualitative evaluation of uncertainty in activity data, EFs, and estimates to improve transparency and guide improvements.

Quality Assurance/Quality Control (QA/QC) Planned system of checks, reviews, and documentation to improve transparency, consistency, comparability, completeness, and accuracy of GHG inventories.

Decision tree Structured flowchart to select appropriate Tier methods based on data availability, key category status, and measurement options.

Oxidation factor (OF) Fraction of carbon in fuel oxidised to CO_2 during combustion.

Net calorific value (NCV) Basis for default stationary combustion EFs (kg GHG per TJ).

Technology-specific emission factor Emission factor reflecting fuel and technology (combustion type, controls, operating conditions) used in Tier 3 methods.

Continuous emissions monitoring (CEM)	Continuous monitoring of flue gases at facilities; useful for solid fuels, variable fuels, requires robust QA/QC.
Calcination	Thermal decomposition of carbonates releasing CO_2 (e.g., $CaCO_3$ + heat → CaO + CO_2); primary pathway for carbonate-related process CO_2.

Non-technical summary

Industrial activities are a major source of greenhouse gas (GHG) emissions, driven by both fuel combustion and process-related chemical reactions, accounting for roughly one-fifth of the global GHG emissions. They are thus of key importance for national climate strategies and for global efforts to limit global warming.

The Enhanced Transparency Framework (ETF) under the Paris Agreement requires countries to submit Biennial Transparency Reports (BTR), including National Inventory Reports (NIR), and makes robust, consistent industrial-sector inventories essential for meeting international obligations and informing national decarbonisation strategies. In national GHG inventories, emissions from industrial activities are reported across two sectors[1]: Energy (fuel combustion in industry) and Industrial Processes and Product Use (IPPU).

This document aims to support GHG inventory compilers with the implementation of the 2006 IPCC Guidelines of National Greenhouse Gas Inventories (and, where applicable, the 2019 Refinement[2]) by translating core methods into practical, step-by-step guidance, supported with practical examples that national GHG inventory compilers can adopt. It focuses on the high-emitting industrial subsectors (e.g., cement, iron and steel, and chemical industry), provides guidance on methodological choices, and offers actionable advice on data collection, Quality Assurance /Quality Control (QA/QC), and time series management.

This aligns with the efforts of the Climate Club[3] and other initiatives to decarbonise the industrial sector, as robust transparency systems are essential for designing and guiding decarbonisation policies. The Climate Club aims to increase ambition and accelerate action on industrial decarbonisation. It brings together countries that are committed to common climate policies and regulatory standards, with a particular focus on the steel and cement sectors. In addition, it promotes international cooperation through its Global Matchmaking Platform, which has already been used by several countries to request and receive support on monitoring, reporting and verification (MRV) of industry-related GHG emissions.

This guide helps experts compiling national GHG inventories and climate policy in the industrial sector:

- Understanding the main sources of GHG emissions of high-emitting industrial categories;
- Learning from good practice examples in cooperation with the (private) industrial sector for data collection;
- Selecting appropriate GHG estimation methodologies;
- Progressively improving methods and data in line with IPCC good practice and ETF requirements.

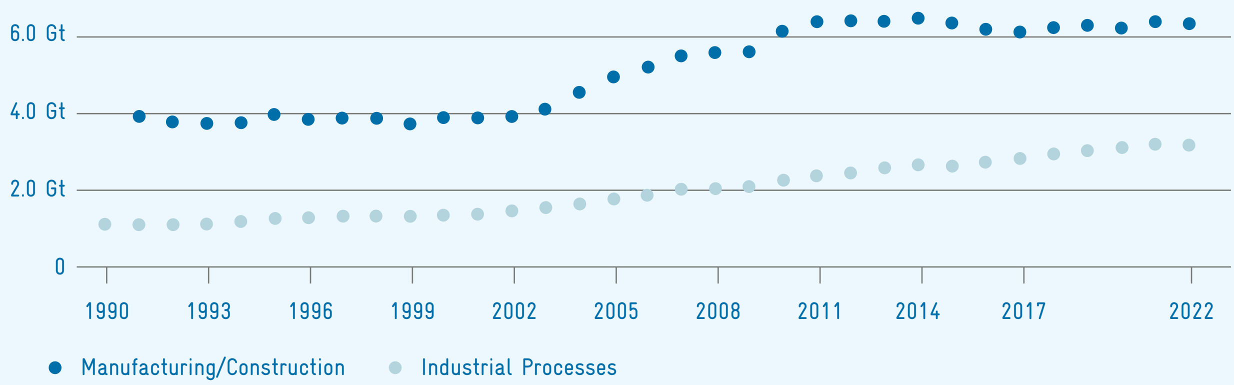
1 These are sectors as defined in the IPCC 2006 Guidelines for National GHG Inventories.
2 The 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories provides methodological improvements and updates to the 2006 Guidelines.
3 https://climate-club.org/

1 Introduction

The industrial sector encompasses a wide range of activities related to the transformation of raw materials into finished goods through manufacturing processes. It includes a diverse range of industries: iron and steel production, cement manufacturing, production of chemicals and petrochemicals, aluminium smelting, paper and pulp production, and various other manufacturing activities. Globally, the industrial sector is a critical driver of economic growth and employment, providing essential materials and products that support infrastructure development, construction, transportation, and consumer goods production. The sector's contribution to national economies varies significantly across countries, with developing nations often experiencing rapid industrial growth, as they build their manufacturing capabilities.

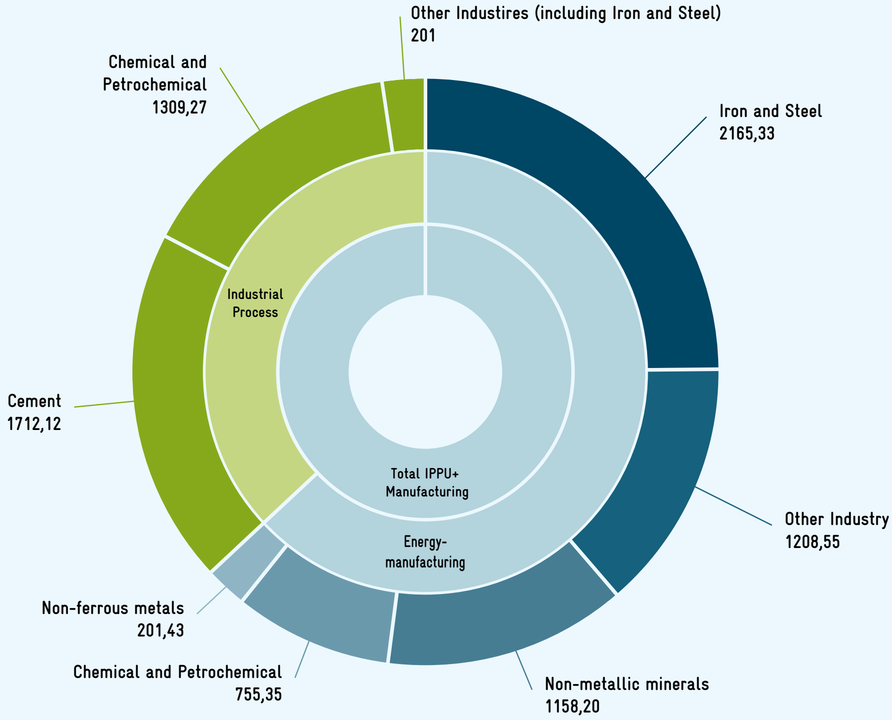
Industrial activities are among the most significant contributors to global greenhouse gas (GHG) emissions. The emission profile of the industry is characterised by both energy-related emissions from fuel combustion for heating, electricity generation, and mechanical processes, as well as process emissions that result directly from chemical reactions or physical processes during production. Between 1990 and 2022, industrial emissions showed a concerning growth trend, with industrial processes experiencing the fastest growth rate at 225%, while fuel combustion for manufacturing and construction increased by 60% (Figure 1) (Climate Watch, n.d.). This growth reflects the rapid industrialisation in developing countries and increased global demand for industrial products. Most industrial emissions consist of Carbon Dioxide (CO_2) (74% of total GHG emissions), primarily from fossil fuel combustion and process-related chemical reactions. The sector also emits methane (CH_4) and nitrous oxide (N_2O) from chemical processes, and fluorinated gases (F-gases) from specialised industrial applications (Hannah Ritchie et al., 2020).

Figure 1: Historical industrial GHG emissions



Industrial activities were responsible for approximately 20% of the total global emissions in 2021, understood as the sum of direct process emissions (6.5%) and emissions from fuel combustion for manufacturing and construction (12.7%) (World Resources Institute, 2025). Key emitting industries include iron and steel production, cement manufacturing, and chemicals and petrochemicals industry, which contribute approximately 4% each to the global GHG emissions through process emissions and fuel combustion (Figure 2) (World Resources Institute, 2025).

Figure 2: GHG emissions from fuel combustion and processes in industrial activities, in Mt CO2eq[4]



Industrial decarbonisation has become a critical priority for reducing GHG emissions amid intensifying global efforts to combat climate change. Improving energy efficiency, switching to cleaner fuels and electricity, putting carbon capture and storage technologies into practice, creating ground-breaking technologies like hydrogen-based steel production, and encouraging circular economy principles to lower material demand and waste generation are some potential GHG reduction strategies for the industry.

Under the United Nations Framework Convention on Climate Change (UNFCCC), countries' GHG emissions were reported through the Measurement, Reporting and Verification (MRV) framework under National Communications and Biennial Update Reports (BURs) in the past. With the adoption of the Paris Agreement in 2015 (UNFCCC, 2015), the Enhanced Transparency Framework (ETF) was established and came into effect in December 2024. To date (e.g. as of 03/2026), 131 BTRs have been submitted. Second BTRs are due in December 2026. According to the Modalities, Procedures and Guidelines (MPGs) (UNFCCC, 2018) for the ETF, all Parties are required to submit their Biennial Transparency Reports (BTRs), containing information on their National Inventory Reports (NIRs), and on progress made in implementing and achieving National Determined Contributions (NDCs). Parties can also decide to report on adaptation actions and the support received. The reporting requirements and BTR chapters are presented in Figure 3. Developing countries have flexibility to report in accordance with their capacities, particularly regarding the scope, frequency, and level of detail. However, all countries are expected to improve their reporting quality (and frequency) over time.

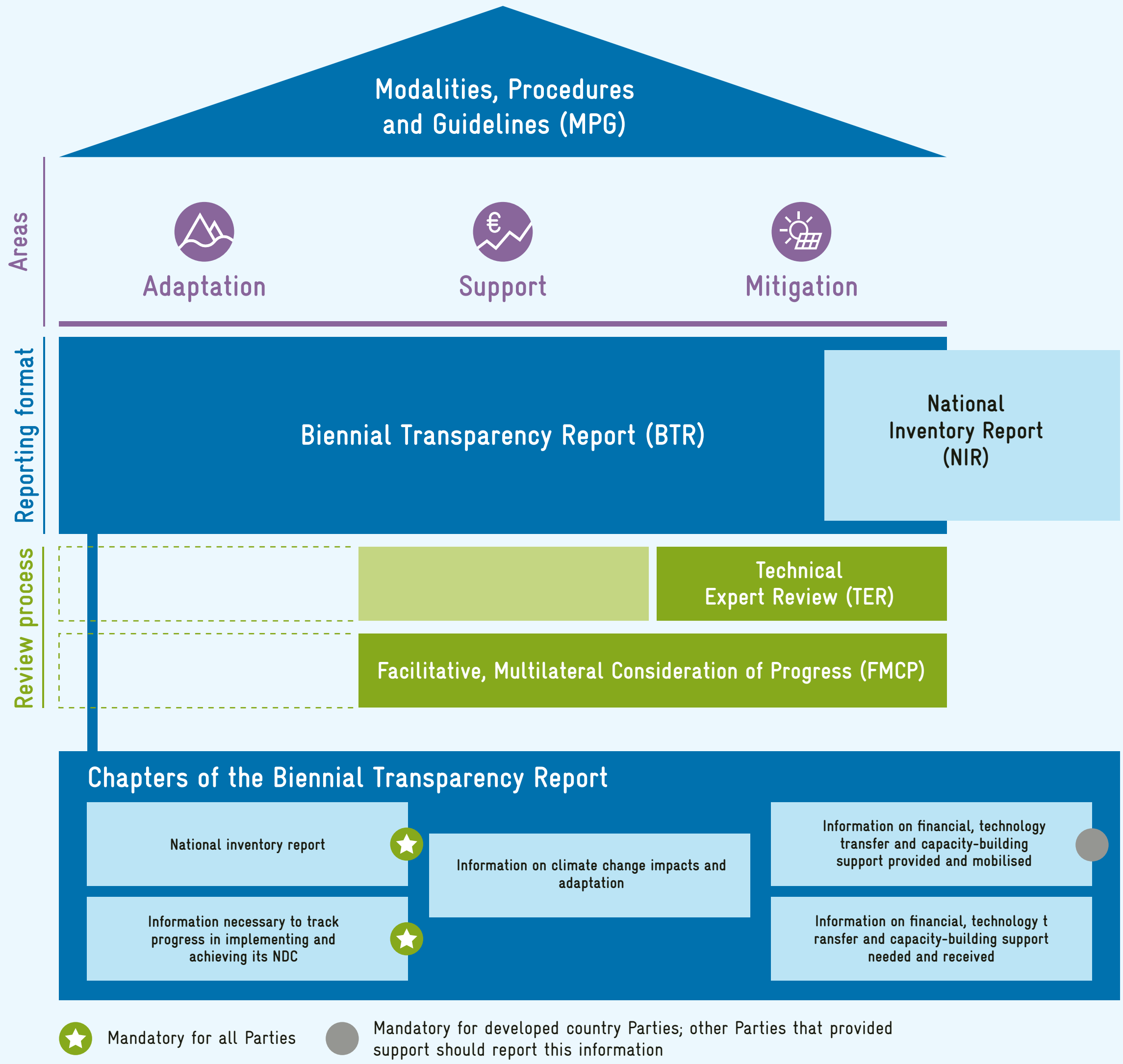
Accurate and transparent reporting of industrial emissions is essential for meeting international obligations under the Paris Agreement, informing national policy and decarbonisation strategies and contributing to the overall integrity of the global climate regime. The Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines for national GHG inventories (IPCC, 2006a) (from here on referred to

4 Own adaptation from World Resources Institute (2025)

as the 2006 IPCC Guidelines) provide internationally agreed methods and good practices for countries to estimate and report their GHG emissions. According to the 2006 IPCC Guidelines, emissions associated with industrial activities fall under two main sectors:

- Industrial Processes and Product Use (IPPU): This covers emissions from activities related to physical or chemical processes that occur during the production of goods such as cement, chemicals, and metals, as well as the use of products that release GHG during their life cycle. The IPPU sector does not include emissions from combustion, which are reported under the Energy sector.
- Energy: This includes emissions from fuel combustion in industry, including fuel combustion for the generation of electricity and heat for these industry processes.

Figure 3: Reporting under the Enhanced Transparency Framework[5]



5 Reprinted from Harries et al. (2023).

1.1 Purpose of the guide

Accurate and reliable GHG emissions data of industrial activities is crucial for the planning and implementation of effective mitigation actions. As countries commit to increasingly ambitious climate targets under the Paris Agreement, the industry sector presents both significant challenges and opportunities for GHG emissions reduction. Robust GHG measurement and reporting frameworks play a key role in tracking progress, determine the impact of energy-efficiency measures, and supporting compliance with national and international requirements. National priorities and international initiatives such as the Climate Club's objectives—particularly accelerating sectoral decarbonisation in emission-intensive industries and promoting ambitious and transparent mitigation policies—rely fundamentally on robust and comprehensive GHG inventories. Such inventories enable evidence-based decision-making and facilitate the sharing of good practices.

Box 1: Climate Club

The Climate Club is an open and inclusive high-level forum for countries aiming at accelerating action and increasing ambition, especially in the industry sector. It focuses on the emission intensive steel and cement sectors, often referred to as “hard-to-abate” as technologies for low-carbon steel and cement are still emerging and costly.

It pursues a comprehensive approach with work on direct measures in the industrial sector, especially steel and cement, overarching questions about the mix of policy instruments, and the prevention of carbon leakage as well as support for developing and emerging countries. International cooperation is facilitated through the Global Matchmaking Platform (GMP) of the Climate Club, which helps to coordinate and accelerate the delivery of support for industrial decarbonisation. Several countries requested support for the development and improvement of monitoring systems for emissions in the industry sector through the GMP, showing that transparency is an important topic for emerging markets and developing economies. Since its launch in 2023, the Climate Club membership grew to 48 countries (as of 01.2026), making it a key initiative in the field of industry decarbonisation.

Further information is available at https://climate-club.org/.

Many countries are unaware of the sources of industrial emissions within their borders.[6] Developing countries often face challenges such as limited availability of statistical data, insufficient collaboration with private and industrial sectors in data collection and reporting, and inadequate institutional and regulatory frameworks for effective GHG mitigation. These constraints directly undermine countries' ability to develop effective mitigation strategies, track progress toward their Nationally Determined Contributions (NDCs), and participate meaningfully in international cooperation mechanisms such as the Climate Club (see box 1).

This guide includes good practice examples to support the preparation of GHG inventories of the emissions from industrial activities. It complements the 2006 IPCC Guidelines, demonstrating how countries have addressed common challenges. For general guidance on MRV systems, please consult the UNFCCC's Handbook on Institutional Arrangements to Support MRV/Transparency of Climate Action and Support.

The guide is addressed at experts involved in compiling national GHG inventories with regards to industrial activities, particularly in developing countries. Drawing on the 2006 IPCC Guidelines, the IPCC 2019 Refinement

6 Based on the review of challenges with industry GHG emission accounting, based on Climate Club Member country reports (see Annex I for full list).

(from here on referred to as the 2019 Refinement)[7], and the country experiences, the guide presents specific recommendations for all key GHG emissions sources related to industrial activities.

This guide defines "industrial activities" as the manufacturing and processing of goods, with a focus on heavy industry sectors such as cement, chemicals, and metals.

Following this introductory Chapter 1, Chapter 2 provides practical guidance on compiling GHG inventories and the basics of estimating greenhouse gas emissions from industrial activities. Methodological guidance for estimating CO_2, CH_4, and N_2O emissions from fuel combustion is presented in Section 2.3 (Stationary Combustion), as the calculation approach is identical across all industrial categories.

Chapter 3 presents detailed step-by-step methodological approaches for process emissions from focus sectors:

- Section 3.1: Cement production
- Section 3.2: Metal production
- Section 3.3: Ammonia production

Each section addresses activity data considerations specific to the fuel use in that industry. Chapter 3 furthermore includes good practices for data collection for national GHG inventories in Section 3.4.

Annex I lists the countries included in the study. Annex II links to all publicly available documents and useful resources. The bibliography contains all the resources used in compiling this study.

This icon indicates a good practice for that specific sector.

7 Under the ETF, all Parties are required to use the 2006 IPCC Guidelines as the primary methodology and are encouraged to incorporate updates from the 2019 IPCC Refinement where possible (UNFCCC 2019). Therefore, this study focuses on the methods contained in the 2006 IPCC Guidelines with references to 2019 Refinement, where appropriate.

Harnessing Transparency for Industry Decarbonisation - Good Practices in Greenhouse Gas Inventory Compilation for the Industry Sector

	Chapter 1 Introduction	Chapter 2 Methodological Guidelines & Best Practices on National GHG Inventories	Chapter 3 Step-by-Step Methodological Approaches for Process Emissions	Chapter 4 Practical Approaches for Data Collection	Chapter 5 Useful Resources
Topics Covered	• Background: global GHG emission trends in industry • Purpose of the guide • Reporting under the Enhanced Transparency Framework • Structure of the document	• Overview of GHG accounting approaches (national inventories vs. other frameworks) • Overview of the industry sector in the 2006 IPCC Guidelines • Methodological guidance for fuel combustion	• Methodological guidance on tier selection, activity data and emission factors; and country cases in: • Mineral Industry (cement, lime, glass production and other process use of carbonates): • Metal Industry (iron & steel, ferroalloys and primary aluminium production) • Chemical Industry (ammonia, nitric acid and petrochemical and carbon black production)	• Cross-cutting considerations & overall inventory planning • Roles and responsibilities in inventory elaboration • Data collection: confidentiality & private-sector cooperation • Sectoral considerations for IPPU data management	• Key reference documents and their relevance • Tools, models and databases for IPPU inventories • International initiatives & capacity-building platforms • Links to country reports and case studies
Key Learning Objectives	• Understanding the significance of industrial GHG emissions globally. • Understanding the reporting obligations under the Paris Agreement / ETF. • Identifying the scope and purpose of this guide. • Distinguishing between IPPU and fuel combustion related industrial emissions.	• Navigating the 2006 IPCC Guidelines for IPPU categories. • Selecting appropriate tiers for key industrial subsectors. • Identifying and collecting relevant activity data and emission factors. • Applying good-practice country examples to national contexts.	• Applying step-by-step IPCC methodologies for IPPU categories. • Selecting appropriate tiers for cement, metal and ammonia process emissions. • Identifying sector-specific activity data sources and emission factors. • Learning from country good-practice examples for each subsector.	• Planning and structuring a national IPPU GHG inventory process. • Defining institutional roles and inter-agency coordination. • Developing strategies for engaging industry and handling confidential data. • Applying sector-specific data collection approaches.	• Identifying the most relevant resources for GHG inventory compilation for the industry sector.
	A complement to the 2006 IPCC Guidelines for National GHG Inventories with a focus on industrial emissions targeting government officers in developing countries				

2 Guidance on the methodology and best practices for the compilation of national GHG inventories related to industrial activities

Note to readers:

The following chapters contain detailed technical guidance on greenhouse gas inventory compilation and emission estimation methodologies. Depending on your role and technical background, it may not be necessary to understand every methodological detail. Readers are encouraged to focus on the sections most relevant to their responsibilities and expertise.

This chapter starts with a short overview of various GHG accounting approaches, presenting similarities and differences in national GHG inventory compilation. It then introduces the methodological approaches for estimating GHG emissions from industrial activities as outlined in the 2006 IPCC Guidelines, first at a general level for process and combustion related emissions, and subsequently for each of the source categories addressed by this guide. Case studies from several countries are included to illustrate these approaches in practice.

2.1 National GHG inventories and other GHG accounting approaches

National GHG inventories are the key sources for complete, consistent and accurate data for tracking and reporting GHG emissions trends. They inform policy design and help assess progress toward national and international climate goals. Under the ETF, they are explicitly included as a pillar of transparency, enabling regular reporting, technical expert review, and continuous improvement of reporting practices.

National GHG inventories are only one of many existing GHG accounting approaches. These serve different objectives and differ in the scope covered as well as the accuracy of reporting required. Higher levels of accuracy in GHG accounting are typically required if GHG emissions or reductions are traded, e.g. in Emission Trading Systems (ETS) or offset mechanisms.

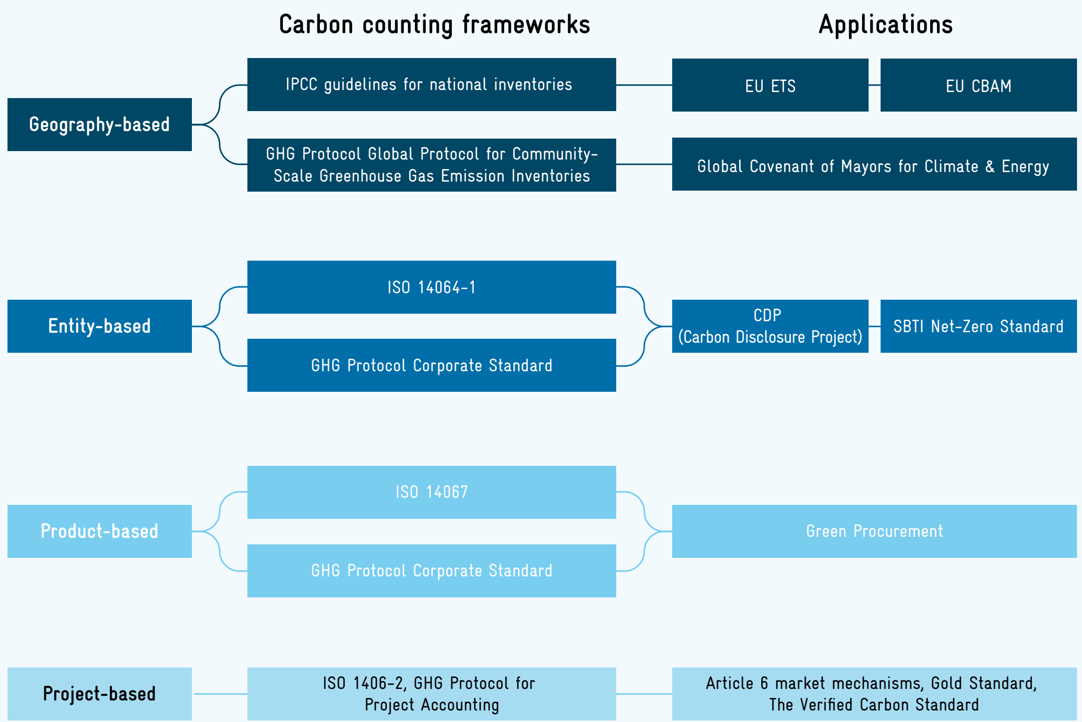
Possible scopes include:

- **Geographical scope:** national, regional, or city-level.
- **Organisational scope:** company, facility or product-level; trade and compliance frameworks define different organisational scopes.

Emissions attribution and generation can include:

- **Scope 1:** directly attributable emissions generated within the geographical or organisational boundary (e.g., fuel combustion, process, and fugitive emissions).
- **Scope 2:** indirectly attributable emissions generated outside the geographical or organisational boundary but consumed within it (e.g., purchased power, heat, or cooling).
- **Scope 3:** indirectly attributable emissions generated outside the geographical or organisational boundary (e.g., value chain emissions).

Figure 4: Overview of different accounting frameworks and their applications[8]



At **national** level, national GHG inventories provide a nationwide understanding on all anthropogenic sources and sinks of GHG emissions and support assessing progress toward national and international climate goals. National GHG inventories are compiled using the most recent IPCC guidelines and are submitted under the ETF by all Parties, either as part of the BTR or as an independent National Inventory Document (NID).

Cities play a critical role in climate action, accounting for more than 70% of global energy-related GHG emissions (C40 Cities, 2016). They are increasingly recognised as key actors in achieving national and global climate targets. Many cities report their GHG emissions as part of commitments to international initiatives, such as the Global Covenant of Mayors for Climate & Energy and the C40 Cities network, to track progress toward their own climate action plans and net-zero targets, and to demonstrate their contribution to national climate goals. The GHG Protocol's Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC)—developed by the World Resources Institute, Cities Climate Leadership Group (C40), and ICLEI-Local Governments for Sustainability—provides a framework for accounting and reporting city-wide emissions, with its latest version (GPC 1.1) revised to align with the IPCC 2019 Refinement. City-level inventories most frequently cover scopes 1 and 2, sometimes also scope 3.

Corporate accounting (e.g., GHG Protocol Corporate Standard, ISO 14064-1) quantifies organisation-level emissions—including value-chain scopes 1-3 as appropriate—for disclosure, target-setting, and interaction with policy instruments. **Product-level accounting** (e.g., ISO 14067, GHG Protocol Product Standard) quantifies cradle-to-gate footprints[9] to enable procurement decisions, product differentiation, and potential "green premiums" in markets.

8 Own adaptation from Hezir et al. (2025).
9 A Life Cycle Assessment (LCA) that measures a product's GHG impact from raw material extraction ("cradle") up to the point it leaves the factory ("gate"), excluding use and disposal phases, focusing on upstream production.

Project-level GHG accounting quantifies emission reductions from specific mitigation activities by comparing actual project emissions against a baseline scenario representing what would have occurred without the intervention. Under the Paris Agreement, **Article 6** establishes mechanisms for international cooperation on emission reductions. **Article 6.2** enables bilateral or multilateral transfer of **Internationally Transferred Mitigation Outcomes (ITMOs)** between countries to meet their NDCs, while **Article 6.4** establishes a centralized crediting mechanism—supervised by the UNFCCC—that generates verified carbon credits from mitigation projects. A critical accounting requirement under Article 6 is the application of corresponding adjustments, whereby the host country adjusts its national GHG inventory to avoid double counting when emission reductions are transferred internationally. This ensures environmental integrity by guaranteeing that each tonne of CO_2 reduced is only counted once toward climate targets. Beyond compliance markets, voluntary carbon markets also use project-level accounting to generate offsets certified by independent standards (e.g., Verra VCS, Gold Standard), allowing companies and individuals to compensate for their emissions outside of regulatory frameworks.

Trade and compliance regimes further add requirements to GHG accounting. Emission trading systems (ETS) rely on plant-specific reporting, generally requiring third-party verification of the emission reports. Currently, over 35 countries and sub-national jurisdictions worldwide operate ETS schemes, such as the China National ETS, Canada-Québec Cap-and-Trade System and European Union's (EU) ETS (ICAP, n.d.). The EU Carbon Border Adjustment Mechanism (CBAM) requires reporting embedded emissions for selected imports since 2023 (European Commission, n.d.). This represents the first major CBAM worldwide, while others are emerging. The United Kingdom is introducing its own CBAM in 2027 (GOV.UK, 2025). Australia's Carbon Leakage Review (Australian Government Department of Climate Change, Energy, the Environment and Water, 2025) has recommended a border carbon adjustment focusing initially on cement. Several other countries are actively exploring similar mechanisms to address carbon leakage concerns. With this, harmonisation of reporting requirements and methodologies becomes increasingly important to reduce the compliance burden on international trade. Table 1 gives an overview of key differences between accounting approaches.

Table 1: Key differences between GHG accounting approaches

Approach	Scope of analysis	Primary boundary	Typical data	Main use
National GHG inventory	Country	Sectoral	National statistics, plant data, EFs	UNFCCC/ETF reporting, policy planning
City / Regional GHG inventory	City or region (administrative boundary)	Territorial and/or consumption-based (Scopes 1, 2, and optionally 3)	Local statistics, utility data, regional activity data, downscaled national data	Local climate action planning, tracking municipal targets, urban policy development
Corporate	Organisation	Scopes 1–3 across value chain	Metered use, company records, supplier data	Targets, disclosure, comparability
Project Accounting	Specific project or activity	Project boundary (baseline vs. project scenario)	Project-specific activity data, baseline emissions, monitoring reports, corresponding adjustments	ITMOs transfer (Article 6.2); Article 6.4 crediting mechanism; voluntary emission reductions for offsetting

Approach	Scope of analysis	Primary boundary	Typical data	Main use
Product Life Cycle Assessment	Product	Cradle to gate/use/ end of life	Process/bill of materials data	Labels, procurement, green premiums
CBAM	Imported product (cement, iron and steel, aluminium, fertilizers, electric and hydrogen)	Embedded emissions	Facility/process footprints per product	Border adjustment to EU ETS price
ETS	Installation/facility	Specific emission sources with requirements for measured fuel/ material flows	Metered fuel/material or output, supplier data	Compliance trading

Despite different goals, these approaches share core foundations: clear system boundaries, robust activity data, appropriate Emission Factors (EFs), and quality assurance/quality control (QA/QC) processes to manage uncertainty and improve reliability. This creates a significant opportunity to use the data collected for multiple purposes, especially as carbon pricing and low-carbon product markets expand. Making these frameworks interoperable is increasingly a priority, as it can reduce compliance burdens and enable comparable product-level intensity metrics. However, interoperability also introduces a major risk of double counting of indirect emissions across product and entity accounting. Many stakeholders favour mutual recognition over a single global carbon accounting standard—particularly to accommodate developing countries' capacity constraints (Clarissa Lins, Bruna Mascotte, Tamara Dain, 2025). At the same time, common technical challenges persist across frameworks, including boundary definitions, reliance on default versus primary data, allocation of shared GHG emissions across different co-products, and risks of double counting of indirect emissions in product/entity accounting.

For national GHG inventory compilers, two practical implications stand out:

- First, clearly separating emissions from combustion of fuels and emissions from IPPU when reusing facility or corporate/product data in national inventories, including by aligning boundaries early.

Second, anticipating external requests (e.g., CBAM, sectoral/product-intensity labels) for verifiable product-level data and being ready to explain methodological choices around boundaries, EFs, co-products, units, and treatment of indirect emissions. This would help ensure credibility across regimes. Box 2 explains how national GHG inventory compilers could use the requirements of CBAM[10] reporting to improve their national GHG inventories.

Box 2: The role of the EU CBAM

The EU's CBAM encourages cleaner industrial production globally. It ensures that products from jurisdictions with less stringent climate policies face comparable carbon pricing when entering the EU market. This levels the playing field with the EU producers subject to the EU ETS and incentivises EU based and EU export-oriented companies to reduce their GHG emissions. CBAM applies a carbon price to imported goods, including iron and steel products.

10 More information on CBAM can be found at https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en.

Since 1 August 2024, declarants must report installation emissions, and the European Commission may review these reports. From 2026, the definitive regime will require importers to purchase CBAM certificates for embedded emissions for the following product categories: cement, iron and steel, aluminium, fertilisers, electric and hydrogen. Detailed rules will be set through implementing and delegated acts, including methodologies and provisions on adjusting for EU ETS free allocation and deducting carbon prices paid in third countries.

CBAM requires importers to report the "embedded direct and indirect emissions" of their products using the CBAM methods. This includes a clear understanding of production processes and the associated emissions, the definition of installation boundaries, and the selection of calculation methods as per the IPCC Guidelines.

To reduce the additional reporting requirements, national GHG inventory compilers could consider the following practices:

- Mapping IPCC categories to CBAM Combined Nomenclature[11] (CN) goods for the three sectors. This helps trace data from national systems to product-level reporting.
- Considering aligning IPCC methodologies with CBAM calculation options where this seems appropriate and enhances quality of emission estimation. This could be done by strengthening plant-level data collection and building a national EF repository to support both national estimates and CBAM installation reporting.
- Enhancing QA/QC and uncertainty management, focus checks on key categories relevant to CBAM.
- Sharing standardised templates and guidance with domestic producers exporting to the EU, so their installation data meet CBAM registry expectations and declarant needs.

Türkiye's Climate Law mandates an installation-level CO_2 monitoring for plants emitting more than 50,000 t CO_2eq per year. It applies and requires third-party verification, mirroring EU ETS rules. The central registry system, that stores all the monitoring, annual and verification reports of the plants, could enable Turkish steel, cement, and fertiliser exporters to supply CBAM-compatible data without additional reporting layers.

2.2 Overview of developing and reporting national GHG inventories

This section provides a brief overview of the key steps and good practice examples for compiling national GHG inventories[12].

Developing and reporting a national GHG inventory typically follows a recurring cycle that includes planning and method selection, data collection and quality control, emission estimation with key category analysis, drafting and QA/QC, finalisation with archiving and reporting, and a structured improvement phase for subsequent submissions (IPCC, 2006b), as shown in Figure 5 below. Furthermore, Table 2 lists the information that should be reported in the national GHG inventories.

11 The CN is a tool for classifying goods, established to meet the requirements of both the Common Customs Tariff and the EU's external trade statistics. In the context of CBAM, CN codes determine whether imported products are subject to CBAM reporting and payment obligations based on their classification when they cross the EU border.

12 More detailed information on each compilation step can be found in Chapter 2 of the paper Good Practices in GHG Inventories for the Waste Sector from Partnership on Transparency in the Paris Agreement (PATPA).

Table 2: Information to be reported in the national GHG inventories

Sector coverage	The IPCC 2006 Guidelines and 2019 Refinement require reporting under four sectors: **Energy:** fuel combustion and fugitive emissions, including energy industries, manufacturing, transport and others. **IPPU:** process-related emissions from production and product uses. **AFOLU:** Agriculture, Forestry, and Other Land Use Activities. **Waste:** solid waste disposal, biological treatment of solid waste, incineration/open burning, and wastewater.
GHGs	CO_2, CH_4, N_2O, and fluorinated gases (HFCs, PFCs, SF_6 and NF_3). Gases should be reported separately for each sector and subsector.
Methodological Tier	The level of methodological detail used to estimate emissions for each category and gas ranging from 1 to 3. For more information on Tiers see Section 2.3.1.
Activity data	The quantitative measures of an GHG emission generating activity. The amount and unit (e.g., fuel consumption in TJ for stationary combustion or clinker/cement production mass) of activity data should be provided, along with the sources and details of any conversions.
Emissions Factors	The coefficients that quantify the mass of a greenhouse gas emitted per unit of activity. GHG emissions are estimated emissions by multiplying activity data with EFs. EFs may be expressed per energy (e.g., kg CO_2/TJ) or mass/volume units. The sources of the EF should be reported.
Key category analysis	The method to identify which categories and gases contribute most to the national inventory's emission level and/or trend. The method used and the results should be reported.
Time series	Annual time series with consistent methods, activity data, and EF; recalculated to maintain consistency when methods change.
Uncertainty	The quantified and qualitatively described degree of possible deviation in GHG estimates due to data and method limitations (e.g., input data errors, incomplete coverage). Uncertainties for categories and totals (at least for the starting and latest year) and trend uncertainty should be estimated to prioritise improvements.
Quality Assurance/ Quality Control (QA/QC) and docu-mentation	**QC** comprises routine checks during national GHG inventory preparation to minimise errors in data and calculations. **QA** assesses, after compilation, whether the chosen methods and data are appropriate. Systematic recording and archiving of data sources, assumptions, methods, calculations, and QA/QC procedures ensures transparency, consistency, comparability, and reproducibility. It is good practice to prepare archives alongside the final national GHG inventory report.

Figure 5: National GHG inventory cycle[13]

When compiling this information, the following issues should be considered:

Identifying key categories: A source refers to a specific physical process or activity that releases GHGs into the atmosphere (e.g., stationary combustion of fuels and calcination of limestone), whereas a category refers to the classification system (e.g. 1.A Fuel Combustion Activities and 2.A.1 Cement Production) used in the 2006 IPCC Guidelines. Sources are grouped into categories. Identifying the most relevant categories of emissions in the country ("key categories") helps national GHG inventory compilers focus their efforts and achieve a higher quality estimation for these. The 2006 IPCC Guidelines provide two main approaches to identify the key categories of the national emissions, with two assessments each:

- **Approach 1 - Level Assessment** is based on previous emission estimates and focuses on level assessment. This approach identifies categories by ranking them in descending order of magnitude according to their contribution to absolute emissions. Categories are summed cumulatively until reaching a predetermined threshold (typically 95% of total emissions), though developing countries with capacity constraints may use a lower threshold (as low as 85%).
- **Approach 2 - Trend Assessment** builds upon Approach 1 by incorporating both previous and current emission estimates and their associated uncertainties to conduct trend assessment. This approach helps identify categories where emissions are growing or declining rapidly and which influence the trend in the total emissions between the first and last reporting year the most.

Alternatively, **qualitative assessment** can be used where the quantitative assessments could not be carried out due to lack of data. Qualitative assessments could also be used to identify sources expected to become important in the future due to policy changes or economic development.

Choosing the right methods for compiling a GHG inventory depends on:

13 Reprinted from Partnership on Transparency in the Paris Agreement (2022).

- Which emission categories and gases most influence the inventory totals (key categories).
- What data and resources are available in the country.

For the key categories, it is good practice to use at least a Tier 2 approach, which in most cases means using national-level activity data and country-specific EFs. Where countries can justify that they cannot apply this approach for key categories, despite their best efforts, they can start with generalised data provided by the IPCC and improve over time (UNFCCC, 2018) (see Section 2.3.2 for more details).

For instance, if a country's CO_2 emissions from cement production have been identified as a key category, the national GHG inventory team should try to use country-specific EFs or facility-level data rather than the IPCC default values.

Building complete and consistent time series: It is important to estimate the GHG emissions for all years covered by the National Inventory Report (e.g. 1990-2024). The 2006 IPCC Guidelines and the 2019 Refinement provide methods to fill data gaps. Default values or expert judgement can be used initially, but countries should aim to replace these with country-specific data when it becomes available, especially for important categories. Ensuring **time series consistency** is equally critical to avoid breaks in the data. This can be achieved by using a consistent method to estimate emissions across all years. When methodologies must change, e.g., when moving from a lower Tier to a higher Tier, it is good practice to recalculate the entire time series using the updated approach. Where full recalculation is not possible due to the lack of data, techniques such as interpolation or extrapolation may be used to maintain consistency.

Interpolation is a method used to estimate missing data points **within** a known data range. In GHG accounting, this is applied when activity data or EFs are available for certain years, but data for intermediate years are missing.

Example: If a country has cement production data for 2015 and 2020, but not for 2017, interpolation can be used to estimate the 2017 value based on the trend between the two known data points.

Extrapolation is used to estimate data points **beyond** the range of known data. This is often applied to extend a time series forward or backward when recent or historical data are unavailable.

Example: If the most recent energy consumption data available is from 2022, but the inventory year is 2024, extrapolation can be used to estimate 2024 values based on historical trends or proxy indicators (e.g., GDP growth, production indices).

Understanding and reducing uncertainty: Certain sectors and categories are more difficult to calculate than others, e.g., for forestry and land-use emissions, uncertainties can be ten times higher than uncertainties related to process or combustion emissions from industrial activities. By assessing uncertainties and comparing them to the typical values as provided by the 2006 IPCC Guidelines, national GHG inventory compilers can focus on inventory improvements with the greatest impact. It is helpful to report on the uncertainty of emissions trends between the first and the last reporting year.

QA and QC should be built into the process through a formal plan that assigns clear roles and responsibilities, describes what checks to perform and when, and sets standards for documentation. Regular quality checks during every step help catch errors, preserve knowledge when staff change, and make improvements easier over time. A review after completing the inventory is also advisable.

An improvement plan allows to progressively enhance the quality, accuracy, and completeness of a national GHG inventory. It involves identifying gaps in current methods and data, prioritising improvements based on key categories and uncertainty levels, as well as defining specific actions with clear timelines and responsibilities. Typical improvements include transitioning from default to country-specific or plant-level methodologies, establishing data-sharing agreements with industry stakeholders, and strengthening QA/QC procedures.

Documenting and archiving facilitate an efficient compilation of national GHG inventories, as the information from previous compilation cycles is readily available and organised. This includes data, data sources, assumptions, methodologies used, intermediate and final calculations, key communication (e.g. emails with data providers), as well as the compilation, QA/QC, and improvement plans. This structured approach makes each new inventory compilation more efficient.

2.3 Overview of the industry sector in the IPCC guidelines

Industry GHG emissions considered in this guide come from two sectors of the 2006 IPCC Guidelines:

- Energy: emissions from combusting fuels in industrial facilities.
- IPPU: process-related emissions from industrial facilities.

The energy sector covers fuel combustion under various categories, including, among others, “Energy Industries (category 1.A.1)” and “Manufacturing Industries and Construction (category 1.A.2)”. The GHG emissions from fuel combustion in industrial facilities are reported under category 1.A.2, by subcategories that are aligned to International Standard Industrial Classification (ISIC), including:

- Iron and steel
- Non-ferrous metals
- Chemicals
- Pulp, paper and print
- Food processing, beverages and tobacco
- Non-metallic minerals
- Transport equipment
- Machinery
- Mining (excluding fuels) and quarrying
- Wood and wood products
- Construction
- Textile and leather
- Non-specified industry

Industrial activities also consume electricity, autogenerated or from the grid. As the IPCC 2006 Guidelines require reporting GHG emissions under the sectors and categories where they occur, emissions from fuel combustion for autogeneration of power in industrial activities fall under category 1.A.2 “Manufacturing industries and construction”. The GHG emissions from fuel combustion at power generators are reported under the category 1.A.1.a “Main Activity Electricity and Heat Production” and does do not fall under the emissions addressed by this guide. The methodologies for the GHG emissions from fuel combustion under 1.A.1.a and 1.A.2 are the same, only the sources differ.

Box 3: Structure of the 2006 IPCC Guidelines

The 2006 IPCC Guidelines are structured into five volumes, each covering a major sector of emissions:

Volume 1: General Guidance and Reporting

- Cross-cutting methodological guidance applicable to all sectors
- Quality assurance/Quality Control (QA/QC) procedures
- Uncertainty assessment and time series consistency

Volume 2: Energy

- Stationary and mobile combustion
- Fugitive emissions from fuels
- CO_2 transport and storage

Volume 3: Industrial Processes and Product Use (IPPU)

- Mineral industry (cement, lime, glass)
- Chemical industry (ammonia, nitric acid, adipic acid)
- Metal industry (iron & steel, aluminium, ferroalloys)
- Non-energy products from fuels and solvent use
- Electronics industry
- Product uses as substitutes for ozone depleting substances (ODS)
- Other product manufacture and use

Volume 4: Agriculture, Forestry, and Other Land Use (AFOLU)

- Livestock emissions (enteric fermentation, manure management)
- Agricultural soils
- Land use, land-use change, and forestry (LULUCF)

Volume 5: Waste

- Solid waste disposal
- Biological treatment of waste
- Incineration and open burning
- Wastewater treatment and discharge

This guide primarily focuses on the mineral, metal and chemical industries, with a specific focus on the production of cement, iron and steel, and ammonia (NH_3). The steel, cement, and (petro-)chemicals industries are particularly important as they generate around 70% of all industrial emissions (TT:CLEAR, n.d.). These industries are often referred to as “hard-to-abate”, as reducing their emissions is especially challenging (TT:CLEAR, n.d.). This choice also supports the Climate Club's mission to decarbonise the emission-intensive steel and cement industries (Climate Club, n.d.). The remaining focus industries are grouped together by subsectors, highlighting common accounting principles as well as the respective specifics. This is because these subsectors are usually less common, less complex or have similar principles for estimating GHG emissions.

The following sections draw upon the methodologies of the 2006 IPCC Guidelines and 2019 Refinement, supplemented by illustrative cases from selected Climate Club member states and/or OECD nations. The NIDs, NCs, Biennial Update Reports (BUR), Biennial Transparency Reports (BTRs), and other relevant national documentation provide the information for the case studies (see Annex I of this document).

2.3.1 Introduction to the Tier approaches under the 2006 IPCC Guidelines

The 2006 IPCC Guidelines use a tiered methodology to balance data availability with accuracy. Decision trees help national GHG inventory compilers select the appropriate methodological level, the "Tier", based on national circumstances and the importance of the source category. Table 3 provides a generic example of a decision tree. Each step requires a check to define which Tier to use and the next actions to take. National GHG inventory compilers should use the decision trees for each source category and all relevant gases.

When considering industrial activities, the Tiers progress from simple to site-specific:

- Tier 1 uses national fuel or production statistics combined with the IPCC default EFs. This is the simplest approach and provides a consistent baseline when higher-tier data are not available. The 2006 IPCC Guidelines provide an Excel file for the Tier 1 approach[14], which can be used with only few additional data inputs. It can also be used as a starting point to estimate emissions using higher Tiers.
- Tier 2 replaces default factors with country-specific EFs derived from national fuel characteristics or process data, typically reducing uncertainty and better reflecting local conditions.
- Tier 3 uses technology-specific or facility-level data (e.g., combustion technology, operating conditions, control technologies), models, and measurements, where available. This Tier provides the highest accuracy when robust data exist.

Table 3: A generic decision tree to choose a methodological Tier.

Step	Checks to be performed	Next action
Step 1	Does the activity, covered by this category, occur in your country? For example, in the metal industry category, is iron and steel or aluminium production carried out in the country?	If yes, go to step 2. If no, emissions under this category are not occurring. Report this fact in the National Inventory Report and use the notation key "NO" in the Common Reporting Tables.
Step 2	According to your previous National GHG Inventory Report, check for each gas under this category (e.g. for CO_2 from cement production) – is it a key category? Early National GHG Inventory Reports might not include a key category analysis or might not cover all categories and/or gases.	If yes, go to step 3. If no, Tier 1 could be used. (Optional: Follow the next steps if resources are available). If your previous National Inventory Report did not include this information, also go to step 3 to assess which Tier you might be able to achieve for the gas and category in question.
Step 3	Are the category specific detailed data available? For example, plant-level activity data, country specific EFs or technology specific parameters.	If yes, use Tier 2 or Tier 3. If no, go to step 4.
Step 4	Can category specific detailed data be collected? Consider the time and resources available.	If yes, collect the data and use Tier 2 or Tier 3. If no, use Tier 1 and provide a justification in the National Inventory Report why higher Tiers could not be applied. Consider the category in the improvement plan for future GHG inventories.

14 https://www.ipcc-nggip.iges.or.jp/public/2006gl/worksheets/2006GL_Worksheets.zip

2.3.2 Emissions from fuel combustion

Emissions from the combustion of fuel in industry arise from across a wide variety of combustion technologies and fuel types. Three main greenhouse gases are released. CO_2, which is the dominant gas and directly linked to the carbon content of the fuel. CH_4, which results from incomplete combustion and varies by combustion technology; and N_2O, which is associated with combustion at lower temperatures or with certain technologies.

The combustion equipment found in industrial facilities varies considerably depending on the subsector. Boilers are widely used for steam generation and process heat, while furnaces are common in metal smelting, glass, and ceramics production. Kilns are central to cement and lime manufacturing. Stationary engines provide onsite power generation; gas turbines are used in combined heat and power systems; and flares are used for waste gas combustion in refineries and chemical plants.

The range of fuels consumed across industrial subsectors is equally diverse. Solid fuels include various grades of coal, such as coking coal, bituminous coal, and anthracite, as well as coke and petroleum coke. Liquid fuels, such as residual fuel oil, gas/diesel oil, naphtha, and liquefied petroleum gases (LPG) are also widely used. On the gaseous side, natural gas is the most common, but industrial byproduct gases such as refinery gas, blast furnace gas, and coke oven gas are also combusted for energy generation. In some industries, such as cement production, biomass and waste-derived fuels also contribute to the fuel mix.

According to the 2006 IPCC Guidelines, Volume 2, Chapter on Stationary Combustion, the GHG emissions from fuel combustion under category 1.A.2 "Manufacturing and Construction" are estimated by multiplying the fuel consumption in energy units, like terajoule (TJ)[15], by the appropriate EFs for each gas and fuel. The sum across fuels gives the category total. Table 4 provides a detailed explanation of how GHG emissions from fuel combustion are calculated for each Tier. These apply to all industrial activities involving the fuel combustion.

The selection of Tiers for fuel combustion follows a decision tree:

- Tier 1 relies on the aggregate national fuel consumption data and default IPCC values for both EFs and net calorific values (NCV). This method is suitable for countries with limited data availability.
- Tier 2 uses the same activity data as Tier 1 but replaces the default EFs and NCVs with country-specific values, leading to more accurate and representative emission estimates.
- Tier 3 applies where detailed facility-level or technology-specific data is available. This Tier offers the highest accuracy and lowest uncertainty but requires significant data and QA.

Table 4: Overview methodological Tiers in fuel combustion

Tier	How to calculate	Key inputs	Typical data sources
Tier 1	Emissions = Fuel Consumption × Emission Factor Sum over all gases and all fuels	Fuel consumption by type in TJ (Convert mass/volume fuel data to energy using default NCVs); Default EFs (kg/TJ) for CO_2, CH_4, N_2O by fuel and technology type; Oxidation factor is assumed to be 1.0.	• National energy statistics • Fuel supply/purchase records • Industry reports • IPCC default EFs and NCVs

15 This is obtained from multiplying fuel consumption in mass by a gross or net calorific value (NCV) for that fuel.

Tier	How to calculate	Key inputs	Typical data sources
Tier 2	Emissions = Fuel Consumption × Emission Factor with country specific EFs replacing defaults Sum over all gases and all fuels	Fuel consumption by type in TJ (converted by using country specific NCVs); Country specific EFs CO_2, CH_4, N_2O by fuel and technology type; Oxidation factor is assumed 1.0 if country specific data is not available.	• National fuel testing/quality programs • Direct measurements at combustion sources • National air quality monitoring programs • Regional EF databases
Tier 3	Emissions by technology = Fuel Consumption$_{fuel}$,technology x Emission Factor$_{GHG\ ,fuel,\ technology}$ Sum over all technologies	Fuel consumption by technology in TJ (converted by using country specific NCVs); For CO_2: Fuel-specific EFs (or country-specific if accounting for incomplete combustion); CH_4, N_2O: Technology-specific EFs by fuel type; Oxidation factor is assumed to be 1.0, if country specific data is not available.	• Plant level fuel use records • Equipment inventories • Technology surveys • Direct emission measurements • IPCC technology specific EFs

2.3.3 Process emissions

Process emissions arise from chemical or physical transformations in industry (e.g., carbonate calcination[16] in cement/lime, chemical reactions in nitric acid). The Tiers are tailored to industrial production data.

- **Tiers 1–2** use the product output or process input consumption with default (Tier 1) or country-specific (Tier 2) EFs per unit of production input or output as appropriate.
- **Tier 3** uses the facility-specific consumption of process inputs, their composition and/or process chemistry; the emissions may also be continuously measured or estimated using models.

The calculation steps for each methodological Tier will be provided in the next chapter under sections 3.1, 3.2, and 3.3 for the mineral, metal, and chemical industries, respectively.

2.3.4 CO_2 Capture

CO_2 capture processes are particularly relevant for industrial processes. The captured CO_2 can be used for long-term storage (Carbon Capture, Utilisation, and Storage – CCUS). The 2006 IPCC Guidelines provides specific guidance on how to report on captured CO_2. This ensures an accurate accounting of emissions.

If a CO_2 capture technology is implemented at a plant, it is a good practice to deduct the captured CO_2 in the emissions calculations, using higher-tier methodologies (Tier 2 or 3). It should be considered that the CO_2 may originate from either combustion or process-related sources. Therefore, double counting of the captured CO_2 under the Energy and IPPU sectors must be avoided.

16 Thermal decomposition of carbonates releasing CO_2 (e.g., $CaCO_3$ + heat → $CaO + CO_2$) – the primary pathway for carbonate-related process CO_2.

3 Guidance on methodology and best practices for process emissions from focus sectors

Note to readers:

The following chapters contain detailed technical guidance on greenhouse gas inventory compilation and emission estimation methodologies. Depending on your role and technical background, it may not be necessary to understand every methodological detail. Readers are encouraged to focus on the sections most relevant to their responsibilities and expertise.

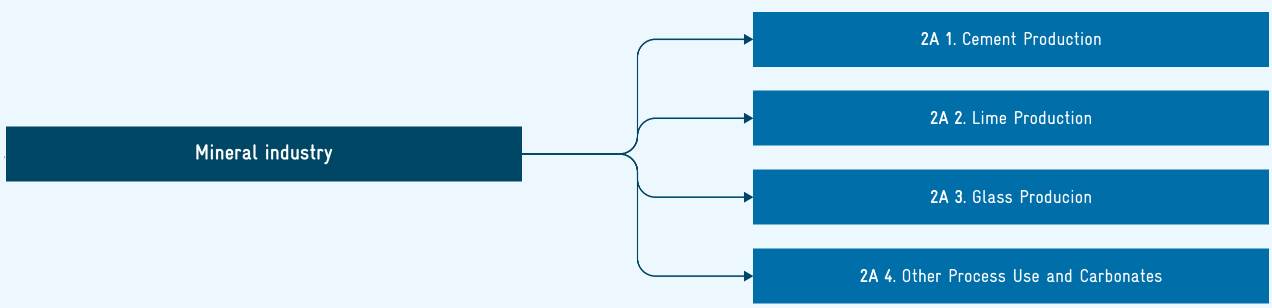
3.1 Mineral industry

The mineral industry accounts for around 7% of the total global GHG emissions (World Economic Forum, 2024a). According to the 2006 IPCC Guidelines, this includes process-related Carbon Dioxide (CO_2) emissions arising primarily from the calcination of carbonate raw materials used to manufacture products such as cement, lime, and glass[17]. These emissions are to be reported according to the inventory categories in Figure 6.

To avoid double counting, national GHG inventory compilers must distinguish between the CO_2 emissions from calcination and those from the combustion of fuels at the producing facilities. Emissions from calcination are reported under the IPPU sector and the emissions from the combustion of fuels (including co-processing of waste as fuels[18]) under the Energy sector, category 1.A.2 “Manufacturing Industries and Construction” (including cement, glass, ceramics, and lime).

The 2006 IPCC Guidelines provide three methodological levels to calculating GHG emissions from calcination of carbonated materials: an input-based (Tier 3) and two output-based (Tier 1 and Tier 2).

Figure 6: IPCC Categories under mineral industry



17 Methane (CH_4) and nitrous oxide (N_2O) emissions from mineral industry processes are assumed negligible in the 2006 IPCC Guidelines under the current state of knowledge.
18 Suitable wastes (e.g., tyres, waste oils, paints) are used in mineral industry as alternative fuels in production kilns (notably, cement), thereby substituting conventional fossil fuels.

3.1.1 Cement production

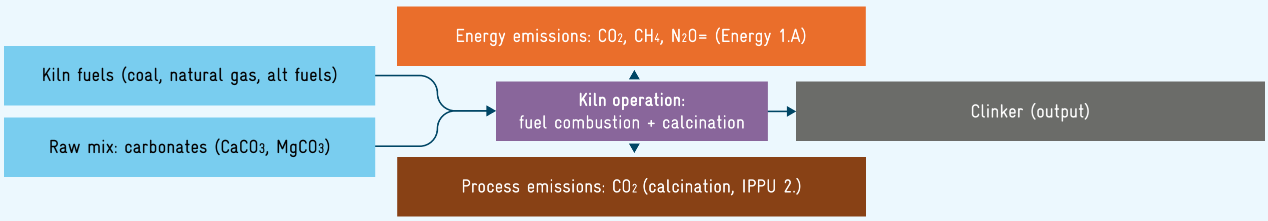
Cement production is a major source of CO_2 emissions in the mineral industry. Most CO_2 emissions come from producing clinker, which requires heating limestone and other raw materials to very high temperatures. It also requires the grinding and blending that happens afterwards. CO_2 emissions from clinker production are estimated by multiplying the **mass of clinker produced** by an **emission factor** and the global average is approximately **0.6 tonnes of CO_2 per tonne of cement produced (IEA, 2023a)**.

Cement kiln dust (CKD), a byproduct containing partially calcined material, needs to be considered. The associated emissions depend on the amount of CKD captured and recycled to the kiln (where the CKD carbonates will be calcined), as opposed to the amount disposed.

The distinction between the emissions from process and fuel combustion is illustrated in Figure 4.

Clinker is the intermediate product formed during cement manufacturing. It is produced by heating a mixture of limestone and other raw materials (such as clay) in a rotary kiln at very high temperatures (around 1,450°C). The resulting clinker nodules are then ground and mixed with small amounts of gypsum to produce cement.

Figure 7: Process and fuel combustion emissions from clinker production



Choice of method

This section focuses on methodological guidance for process emissions, explaining the calculations for Tiers 1, 2, and 3.[19] The calculation steps are summarised in tables with the following colour code. **The blue rows** show the steps to gather data and information before the GHG calculations; **the brown rows** present the main calculation steps with specific parameters and guidance from the 2006 IPCC Guidelines; and **the grey rows** explain the reporting and documentation actions.

TIER 1

National clinker production is estimated from the cement production, disaggregated by type and multiplying each type by its clinker fraction. The inferred total can then be adjusted to account for clinker imports and exports, after which a default EF per tonne of clinker is applied to derive the process emissions. Applying an EF directly to total cement output should be avoided, as it disregards clinker trade. Clinker trade data are typically available in customs and industry statistics. National GHG inventory compilers should make sure that the trade data is purely clinker and does not include other hydraulic cement codes. This method is preferred when clinker production or carbonate input data are unavailable and the category is not a key category. Table 4 provides the calculation steps for Tier 1.

19 Section 2.3.1 above explains the industrial GHG emissions from the combustion of fuels, and this is consistent across all industrial categories.

When compiling the national cement production by type, it is good practice to use representative clinker fractions by type. If a disaggregation by type is not possible, the 2006 IPCC Guidelines provide assumptions on the clinker fraction for different national circumstances.

Table 5: Calculation GHG emissions from cement production using Tier 1 method.

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 1	Compile cement output by type	Sum national cement production by type	Cement type (tonnes)	• National cement statistics • Plant reports	• Confirm totals align with official industry statistics. • Reconcile units.
Step 2	Assign clinker fraction per cement type	Use representative clinker fractions	Clinker Fraction (dimensionless)	National standards or typical recipes; if unknown: • 95% for Portland cement, • 75% for overall output when blends are significant.	• Document assumptions. • Check plausibility against product mix and standards.
Step 3	Adjust for clinker trade	Subtract imports for consumption, add exports produced domestically	Imports (tonnes), Exports (Ex, tonnes) Mass of clinker produced (Mcl, tonnes)	Customs/trade data; Typical tariff codes SITC 661.21 and HTS 2523.10.00 for clinker; ensure distinction from hydraulic cement codes.	Verify codes and avoid mixing clinker vs cement categories.
Step 4	Apply default clinker EF	$CO_2 = [\sum_i(\text{Mass of Cement} \times \text{Clinker Fraction}) - Im + Ex] \times EFclc$	EFclc = 0.52 t CO_2/t clinker (0.51 base + 2% CKD correction)	IPCC default EFclc	Check if all the cement types are included in the calculation.
Step 5	Report and document	Provide assumptions and sources			Explicitly state clinker fractions, trade adjustments, and EF used.

TIER 2

Under Tier 2, the process CO_2 emissions from cement are estimated directly from measured clinker production, multiplied by an EF for clinker (country specific or default), and then adjusted with a correction factor for CKD not recycled to the kiln. The calculation steps for Tier 2 are provided in Table 4.

The **activity data** typically comes from the national statistics or, preferably, plant-level clinker production statistics. Collecting plant-level data can reduce uncertainty and allows documentation of the calcium oxide (CaO) content of the clinker, the share of CaO derived from non-carbonate sources (e.g., slag, fly ash), the CKD generation and recycling practices, which are all relevant to deriving an appropriate clinker EF and CKD correction factor.

The **clinker EF** is derived from the CaO content of clinker that originates from carbonate sources. Where non-carbonate CaO is significant, that portion is excluded before calculating the EF. An explicit correction for Magnesium Oxide (MgO) is generally not required at Tier 2, because MgO in Portland cement clinker[20] is both deliberately kept low and may come from non-carbonate sources.

As a fraction of the **CKD** may be lost and thus not recycled, Tier 2 applies an emissions correction factor to add the associated CO_2 to the clinker-based estimate. In the absence of plant-specific data, a default factor of 1.02 (i.e., +2%) is recommended. If the data are available, it can be computed from the CKD mass, carbonate content, and calcination fraction. Reported additions from lost CKD can range from roughly 1.5% for modern well-controlled plants to about 20%, where highly calcined dust is lost. So, documenting the data source or assumption used is important.

Table 6: Calculation of GHG emissions from cement production using Tier 2 method

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 1	Collect clinker production	Sum national or plant level clinker output	Mcl (tonnes clinker produced)	• Plant reports • National surveys • Industry association statistics	• Reconcile plant data with national totals. • Check time series consistency.
Step 2	Derive clinker EF from CaO	Compute EFcl[20] from CaO in clinker (exclude CaO from non carbonate sources)	EFcl (t CO_2/t clinker) (Clinker CaO%, share of CaO from slags/fly ash. Calcination assumed ~100% for clinker.)		• Validate CaO content is in typical range (60–67%) • Document noncarbonate CaO subtraction
Step 3	Apply CKD correction	Compute CFckd (Correction Factor for CKD)[21]	CFckd (CKD not recycled - Md, raw mix carbonate fraction - Cd, CKD calcination fraction - Fd, EF for the carbonate EFc typically CaCO3= 0.4397, EFcl)	Customs/trade data; Typical tariff codes SITC 661.21 and HTS 2523.10.00 for clinker; ensure distinction from hydraulic cement codes.	Verify codes and avoid mixing clinker vs cement categories.
Step 4	Calculate emissions	CO_2 = Mcl × EFcl × CFckd			Confirm EFcl excludes CKD to avoid double counting. Otherwise the CFckd might be applied more than once.

20 Portland cement clinker consists of a minimum of two-thirds of calcium silicates, specifically (CaO)3SiO2 and (CaO)3SiO2, with the remainder comprising aluminium oxide (Al2O3), iron oxide (Fe2O3), and other oxides (Hannant (2000)).
21 For more information on how to calculate country specific EFcl, see Volume 3, Chapter 2, section 2.2.1.2 of the 2006 IPCC Guidelines.
22 If data is available, the CFckd can be calculated using the Equation 2.5 of Volume 3, Chapter 2 of the 2006 IPCC Guidelines.

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 5	Report and document	Provide EF derivation and CKD assumptions			Record lab methods, sampling frequency, and any MgO consideration (normally not required at Tier 2)

Box 4.

Türkiye uses a Tier 2 methodology by collecting the activity data (clinker production) from individual plants. Türkiye also assessed the country specific CaO content in clinker by collecting data from individual cement plants for the period of 1990-2015. The time series showed that the CaO content does not vary significantly, so the value for 2015 is being used since then.

TIER 3

Under Tier 3, the process CO_2 emissions are calculated from plant-level data based on the mass and composition of all carbonate inputs to the kiln (covering both raw materials and any carbonate in fuels), with the relevant carbonate specific EFs and the fraction of calcination achieved. The approach explicitly accounts for CKD: the CO_2 associated with uncalcined carbonate contained in CKD that is not recycled to the kiln is subtracted from the emission total. The calculation steps for Tier 3 are provided in Table 6.

In practice, material incorporated into clinker can be treated as fully calcined, while the calcination fraction of CKD may be below 100% and more variable. In absence of reliable CKD data, assuming fully calcined CKD makes the CKD correction zero, which is acceptable but may slightly overestimate emissions.

The Tier 3 method relies on stoichiometric EFs[23] for the specific carbonate species. It requires a full accounting of all carbonate sources in the feed mix. Where raw materials contain organic carbon (e.g., kerogen) or carbon residues in non fuel additives (e.g., fly ash), these are typically omitted unless their heat contribution is significant (e.g., exceeding about 5% of total heat). In this case, they are included as non fuel carbon terms in the mass balance.

23 EFs derived from the chemical mass balance of a reaction, representing the theoretical CO_2 released based on the molecular weights of reactants and products, assuming complete conversion.

Table 7: Calculation of GHG emissions from cement production using Tier 3 method

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 1	Compile an inventory of all carbonate inputs	Identify each carbonate species and mass in raw mix and fuels	• M_i by carbonate i (tonnes of carbonate input by type) • Composition of carbonate in the input material(fraction) • Calcination fraction F_i	• Plant lab analyses • Fuel analyses for any carbonate in fuels	Ensure complete coverage of all carbonate sources; set F_i to 1.0 for material incorporated into clinker unless data indicate otherwise.
Step 2	Compute emissions from carbonates	Sum across carbonates	$\sum_i(M_i \times EF_i \times F_i)$ using carbonate specific EF_i	• IPPC values for EF_i[23] • In the absence of actual data of F_i, assume 1.	Apply correct stoichiometric EF per species.
Step 3	Subtract uncalcined carbonate in lost CKD	Deduct the CO_2 that would have been emitted if that carbonate had calcined	$[M_d \times C_d \times (1-F_d) \times EF_d]$ CKD lost M_d, carbonate fraction in CKD C_d, CKD calcination fraction F_d, EF_d (often $CaCO_3$ EF)	If CKD data are unreliable, assume $F_d = 1$, which means no deduction is applied (conservative approach, slight overestimate).	Reconcile Md with plant dust-control and bypass logs. Confirm C_d is consistent with the raw mix carbonate fraction.
Step 4	Account non fuel carbon in raw materials (if significant)	Include kerogen or carbon bearing additives if heat contribution is higher than 5%[24].	$[\sum_k(M_k \times X_k \times EF_k]$ if applicable		Check that energy sector does not already include these process emissions from calcination; document inclusion criteria.
Step 5	Aggregate and report	Sum the results of step 2 and 4 and subtract the result of step 3 at plant level, then aggregate plant-level results to national totals.			Document: all EF sources used, any plant-specific EF derivations, comparison with IPCC defaults, timing of EF recalibrations.

24 The EFs for the particular carbonate can be found in Table 2.1 of Volume 2, Chapter 3 of the 2006 IPCC Guidelines.

25 The 5% threshold refers to the heat (energy) contribution from organic carbon in raw materials (e.g., kerogen in limestone, carbon residues in fly ash) compared to the total heat from fuels used in the kiln. If the heat from these non-fuel carbon sources is less than 5% of the total heat from fuels, their CO_2 emissions may be ignored without significantly affecting accuracy.

Box 5.

Brazil uses plant specific data for cement and clinker production. It applies a Tier 3 methodology for the GHG emissions from cement production, with adjustments made to the 2006 IPCC Guidelines methodology according to the data obtained through the Cement Sustainability Initiative (CSI). Within the CSI methodology, emissions are calculated according to the amounts of CaO and MgO in the clinker.

Brazil demonstrated that both methodologies lead to the same emission results. CO_2 is estimated from clinker chemistry (CaO/MgO), not from raw material input balance that sums carbonate species, calcination fractions, and explicitly subtracts uncalcined CKD not recycled to the kiln, as recommended for Tier 3 in the 2006 IPCC Guidelines.

Brazil collects the data required by the CSI methodology and applies the stoichiometric EFs from the 2006 IPCC Guidelines to calculate the GHG emissions. Annual data collected from each plant includes the CaO and MgO content in clinker, clinker production, purchases and sales, cement output by type, and quantities of mineral additives and CKD used in cement production.

Coal is the **most common fuel used in cement production**, but many cement kilns also burn **waste-derived fuels** like old tires, waste oils, and paints. If the used fuels are unknown, national energy statistics can be used to determine types and quantities of fuels combusted for cement production, using this information under a Tier 1 approach.

If national defaults do not suit local fuel mixes, the IPCC EF Database (EFDB) offers documented factors that may better match national circumstances. The national GHG inventory compiler is responsible for ensuring the appropriate application of these factors. For kilns that co-fire heterogeneous waste-derived fuels, determining their carbon content and selecting a single EF can be challenging. Frequent facility-specific fuel analysis can help.

If a continuous emissions monitoring system (CEMS) is available, the CEMS data can be cross-checked against the sum of calculated combustion and process emissions.

Clinker trade flows—imports and exports—must be carefully considered within the system boundary. Only the **process emissions from clinker production within the reporting country** are included in its national GHG inventory. Emissions related to the imported clinker are part of the national GHG inventory of the producing country. Sierra Leone (Government of Sierra Leone, 2021), for example, produces cement solely from imported clinker and therefore does not report process emissions of the clinker production.

3.1.2 Lime production

The **core applications of lime** are metallurgy, construction, the chemical industry, and environmental management practices, such as flue gas[26] desulphurisation systems or removal of impurities in wastewaters. The steel industry is one the largest consumers of lime, with some estimates of its share of the global consumption at over one-third. The Asia-Pacific region has a high share of emissions due to the demand in steel, paper, construction and water treatment industries. Producing **one tonne of lime emits around one tonne of CO_2** (process and combustion) (IPCC, 2006c).

Lime is made in shaft or rotary kilns at high temperatures. These distinctions affect the EFs and should be reflected in national inventories and methodological choices. Primarily high calcium limestone (calcite, CaCO3) and dolomite are used as a feedstock. The main lime products are high calcium lime (quicklime, CaO), dolomitic lime (CaO·MgO), hydraulic lime (CaO with hydraulic calcium silicates), and hydrated lime.

26 The mixture of gases produced as a by-product of fuel combustion and industrial processes. It is typically exhausted through a chimney or stack and contains GHGs, as well as other combustion by-products such as water vapour, nitrogen oxides (NO_2), sulphur dioxide (SO_2), and particulate matter.

The specific **fuel mix** varies by country and kiln technology, but typical fuels are coal, petroleum coke and coke, residual/heavy fuel oil, gas/diesel oil, other petroleum products, gaseous fuels, natural gas, liquefied petroleum gases (LPG), and process gases where integrated with metals facilities (coke oven gas, blast furnace gas, oxygen steel furnace gas). In mineral industries, some kilns may also use waste fuels (e.g., tyres, waste oils).

Table 8: Overview methodological Tiers in lime production

Tier	What to calculate	Key inputs	Typical data sources
Tier 1	Estimate CO_2 from lime production using default EFs per tonne of lime by type.	• National lime production by type; • Default EF per lime type	• National lime industry statistics • Plant reports • Trade and industry association data
Tier 2	Use national or plant level lime production by type with country specific EFs derived from composition (CaO/MgO) and process data.	• Production by type • CaO and MgO contents • Fraction from non carbonate sources (if any) • Calcination fraction	• Plant lab analyses • National surveys • Industry association data (plant level data)
Tier 3	Carbonate input approach: material balance using masses and compositions of all carbonate inputs to lime kilns, with type specific EFs and calcination fractions.	• Mass and composition of carbonate inputs • calcination fractions • Any dust losses not recycled (if tracked)	• Plant level periodic analyses • Aggregation to national totals for reporting

It is good practice to use at least a Tier 2 methodology, because Tier 1 does not account for Lime Kiln Dust (LKD), which may result in an underestimation of GHG emissions.

It is important to consider that reported lime production often covers only the lime sold on the market, not the lime produced and used on-site as an intermediate product. Many facilities may not report their lime output, e.g., steel, soda ash, calcium carbide, magnesia/magnesium plants, copper smelters, sugar mills, and pulp and paper mills which regenerate lime. These omissions can lead to underestimating the national lime production.

It is good practice to adjust the EFs for the ratio of high calcium lime to dolomitic lime based on the national circumstances. The emissions estimations will be improved if all types of lime are taken into consideration.

Box 6.

Brazil estimates the CO_2 emissions from lime production using a Tier 2 method. Activity data come primarily from the Brazilian Lime Producers Association and the Statistical Yearbook of the Ministry of Mines and Energy. Due to missing updates, 2022 production was held at 2021 levels.

The EFs follow the IPCC stoichiometry (0.785 t CO_2/t quicklime; 0.913 t CO_2/t dolomitic lime) but are adapted to national lime composition and a 95% purity assumption, yielding 0.760 (calcitic), 0.811 (magnesian), and 0.857 (dolomitic) tonnes CO_2 per tonne of lime.

The inventory also distinguishes lime types and adjusts hydrated lime volumes to exclude water: one tonne of quicklime produces 1.27 tonnes of hydrated lime, meaning hydrated lime contains 21.3% water by mass.

3.1.3 Glass production

Glass production has the smallest share in terms of GHG emissions in the mineral industry. The use of recycled glass (cullet) reduces the need for raw carbonates as a process input and lowers process emissions. Moreover, dissolved CO_2 retained in glass is negligible for the national GHG inventory. The emissions from soda ash used in glass production are reported under this category and excluded from "Other Uses of Soda Ash" to avoid double counting. The fuels used in the production of glass are similar to those used for cement and lime, although the use of waste fuels is less common than in the production of cement and lime. Depending on the furnace efficiency and fuel type, a range of **0.5 to 0.7 tonnes of CO_2 is emitted per tonne of glass** (process and combustion) (AGC Glass Europe, n.d.).

It is a good practice to use a Tier 2 or Tier 3 methodology due to the high uncertainty of default factors provided by the 2006 IPCC Guidelines for Tier 1.

The amount of glass products (activity data) is often reported in units of number or area in national statistics, while the 2006 IPCC Guidelines require activity data in mass. Stratifying conversions by glass type or process and converting units within each segment rather than applying a single average across all products will reduce the uncertainty in activity data. The **use of plant-level data** is also a good practice. Otherwise, identifying the cullet ratio for manufacturing of different glass types in the country is essential.

Table 9: Overview methodological Tiers in glass production

Tier	What to calculate	Key inputs	Typical data sources
Tier 1	Estimate CO_2 from glass production using default EFs per glass type, adjusted by recycled glass ratio.	• Glass production by type (e.g., container, flat, fiber, specialty) • Cullet ratio • Default EF	• National glass industry statistics • Plant reports • Cullet usage data • Association publications
Tier 2	Use process specific parameters and country specific EFs based on batch composition and actual carbonate inputs by glass type.	• Batch recipes (carbonate shares, soda ash, limestone) • Cullet ratio • Process parameters • Country specific EF	• Plant level data • Technical specifications, and industry standards
Tier 3	Carbonate input approach: direct accounting of masses and compositions of all carbonate inputs in the batch, with type specific EFs and calcination fractions	• Mass and composition of each carbonate used • Calcination fractions • Cullet ratio • Any retained carbon	• Plant lab analyses • Periodic detailed assessments aggregated nationally

Box 7.

Japan uses Tier 2 to estimate the GHG emissions from glass production. The raw materials used in the processes are limestone, dolomite, soda ash, barium carbonate, potassium carbonate, strontium carbonate and lithium carbonate, based on which the GHG emissions are calculated. Country-specific EFs are calculated based on the proportion of CaO and MgO extractable from the raw materials, as determined by a study conducted by the Japan Lime Association. The following example shows how Japan calculates the emission factor for limestone.

Proportion of CaO extractable from limestone : 55.4 % (Median of 54.8% to 56.0% [b)])

Proportion of MgO extractable from limestone : 0.5 % (Median of 0.0% to 1.0% [b)])

Molecular weight of $CaCO_3$ (primary constituent of limestone) : 100.0869[b)])

Molecular weight of $MgCO_3$: 84.3139[a)]

Molecular weight of CaO : 56.0774[a)]

Molecular weight of MgO: 40.3044[a)]

Molecular weight of CO_2 : 44.0095[a)]

$CaCO_3$ content = proportion of CaO extractable from limestone × molecular weight of $CaCO_3$ / molecular weight of CaO

$MgCO_3$ content = proportion of MgO extractable from limestone × molecular weight of $MgCO_3$ / molecular weight of MgO

Emission factor = (molecular weight of CO_2 / molecular weight of $CaCO_3$ × $CaCO_3$ content) + (molecular weight of CO_2 / molecular weight of $MgCO_3$ × $MgCO_3$ content) = 440 [kg-CO_2/t]

Reference:

a) Atomic Weights of the Elements 1999[http://www.ciaaw.org/pubs/TSAW-1999.pdf] (IUPAC)
b) The Story of Lime

The activity data provided in wet weight is converted to dry weight with the water content of the limestone used for cement. The assumption is that the water content is the same for the limestone, dolomite and soda ash used in glass production.

3.1.4 Other process uses of carbonates

There are process uses of carbonates during which the CO_2 is released (when carbonate minerals are consumed) other than in production of cement, lime, and glass. Examples are ceramics, using soda ash, and producing non-metallurgical magnesia. Similar methods apply when carbonates are used as fluxes (additives) in metal smelting and other industries.

The emissions from process uses of carbonates should be first allocated to the national GHG inventory category where they occur (e.g. cement, lime, glass). Any uncategorised process uses of carbonates should be allocated to "other process uses". Only emissive carbonate uses should be accounted for in national GHG inventories, i.e. processes where carbonates remain chemically unchanged and there are no emissions from calcination should not be included.

Because this industry has many small facilities, detailed information about the specific carbonate composition and the calcination rate of each site may not be available. In these cases, using Tier 2 methods with process-specific adjustment factors is recommended. Different Tiers can be used for different types of carbonate uses, depending on the available data.

Table 10: Overview methodological Tiers in other process uses of carbonates.

Tier	What to calculate	Key inputs	Typical data sources
Tier 1	Estimate CO_2 based on mass of carbonates consumed in emissive uses (e.g., ceramics, soda ash use, non metallurgical magnesia), using default species EFs.	• Carbonate consumption by sector/use • Carbonate species • Default EFs	• Industry statistics • Material purchase/consumption records • Association data
Tier 2	Use process specific data (e.g., fraction of carbonate emitted vs retained in product) and country specific EFs	• Process specific emission fractions • Carbonate sources and species • Retention/storage fractions	• Plant level data • Technical process specifications • Surveys
Tier 3	Carbonate input approach with site specific mass balance: account for all carbonate sources, species specific EFs, and product storage	• Mass/composition of carbonates • Emission fractions • Product storage and non emissive uses	• Detailed plant level mass balances • Laboratory analyses

Box 8.

Other process uses of carbonates is a key category in the national GHG inventory of **Türkiye** as the country produces significant amounts of ceramics. Additionally, Türkiye reports non-metallurgical magnesium production and other uses of soda ash in this category.

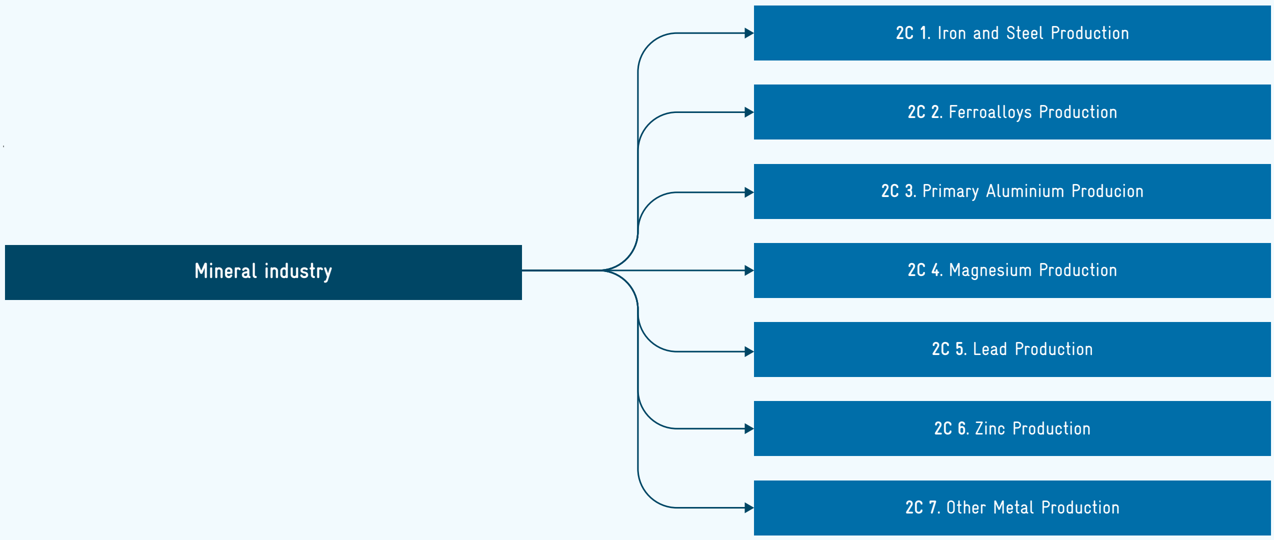
Türkiye uses Tier 2 to estimate the GHG emissions from ceramics production. Calcite, limestone, dolomite, magnesite and hydro-magnesite are consumed as raw materials in the ceramics industry to produce ceramic tiles, sanitary ware, bricks and tile. The data is collected by the Turkish Ceramics Federation and the Turkish Statistical Institute. While the total mass of bricks and tiles are available, the amount of clay used in their production is missing between 2000 and 2004. It is estimated using one of the plant datasets.

The use of soda ash in the glass manufacturing industry is excluded from other uses of soda ash, as it is reported under the glass production category. Türkiye does not gather yearly data on industry-specific soda ash usage. Rather, import data is added to production data, and exports and glass industry usage are subtracted to get the apparent soda ash consumption. All apparent soda ash consumption is assumed to be emissive in this methodology. The two soda ash production facilities provide total production numbers, and TurkStat provides foreign trade information. Glass production data acquired from glass production plants is used to estimate the amount of soda ash utilised in the glass industry.

3.2 Metal Industry

The metal industry is a major source of GHG emissions globally (Lempriere, 2023), with emissions stemming from the combustion of fuels for generating heat or power and from the chemical processes to produce metals. The 2006 IPCC Guidelines, Volume 3 on the IPPU sector, lists the subcategories shown in Figure 8.

Figure 8: IPCC Categories under metal industry



Accurate GHG accounting for the metal industry presents several key challenges:

- The metal industry uses a wide array of production methods, from blast furnaces to more modern electric arc furnaces (EAFs). Each technology has a unique GHG emissions profile.
- The use of different raw materials, such as various grades of coal, coke, or scrap metal, directly affects the carbon content and the emissions. Recommended actions include compiling a "technology matrix" that lists national production by furnace type, feedstock (ore, pellets, direct reduced iron (DRI), scrap), and fuel. This matrix supports activity-data selection and allows calculating weighted Tier 2 or Tier 3 carbon contents where partial plant data exist. It is also important to use the decision-tree figures in the 2006 IPCC Guidelines to justify the selected Tier and to document when a switch to a higher Tier becomes possible as data quality improves. Applying country-specific carbon contents for all major inputs (coking coal, natural gas, scrap) is recommended once this is available. Default factors should be reserved for non-key categories or demonstrably minor flows.
- Plants can be integrated, with multiple processes on a single site, or be at independent facilities that specialise in a single process, such as a stand-alone coke oven plant.

This creates a challenge of setting the system boundaries correctly and allocating emissions between the IPPU and Energy sectors, to avoid double counting. The system boundaries for each facility type could be defined in a narrative form, referencing the IPCC flowchart, so that reviewers can trace every fuel and off-gas (gaseous by-products or waste gases, such as blast furnace gas (BFG) and coke oven gas) stream to a single category. If shared utility units (e.g. captive power plants) serve both metallurgical and non-metallurgical uses, emissions should be allocated according to the "host" sector rule: the on-site use is reported in category 1.A.2.a "Manufacturing Industries and Construction", while the exported energy moves to the relevant energy subcategory. Boundary decisions should be documented in the national GHG inventory methodology report, and any changes to utilities or off-gas routing should be highlighted in the time-series explanation, to ensure transparency and consistency over time. Using Tier 2 or Tier 3 combustion methods for key categories helps to keep the overall uncertainty low.

- Tracking carbon inputs across different feedstocks and complex material flow routes (coal types, coke, scrap metal ratios) and accounting for material recycling rates requires meticulous data systems. A spreadsheet mass balance model that mirrors the IPCC input–output structure can be developed, capturing ore, pellets, pig iron, DRI, scrap, alloying elements, and by-product gases.

Production, import, and export statistics should be cross-checked against the balance to detect missing flows.

- Higher-tier reporting (Tier 2 and Tier 3) requires detailed plant-specific data. Countries may face challenges due to confidentiality concerns from private companies. This can be addressed by creating confidentiality aware templates and non-disclosure agreements (NDAs) to obtain plant level data, aggregating where necessary to protect sensitive information.

The sector itself is undergoing technological transformation, driven by climate policies and industry decarbonisation measures. This includes hydrogen-based technologies, EAFs powered by renewables, usage of secondary metals/metal scraps, and carbon capture solutions (UNIDO, n.d.). These developments can also create new challenges for GHG accounting systems, including the need for new EFs, updated monitoring protocols, revised boundary definitions, and methods to track novel material flows while maintaining methodological consistency over time. Furthermore, it is important to note that reductions from renewables will only be visible in the sector if they replace the power generated at the plant. Aligning these accounting updates with national climate policy frameworks (e.g., NDC targets and measures) and cooperative initiatives (e.g., climate clubs and sectoral alliances) will help ensure transparency, comparability, and credibility of reported progress in the metals industry.

According to the 2006 IPCC Guidelines, the CO_2 and CH_4 emissions from certain carbon sources are reported as industrial process emissions under the IPPU sector. These carbon sources include coke, coal, oil, natural gas, and limestone. They are used as chemical reductants in iron and steel and non-ferrous metal production processes. These processes include sinter, pellet, and BF operations. In contrast, the CO_2 and CH_4 emissions from fuel combustion for coke production are reported under the Energy sector. This includes both fuel consumption and conversion losses.

3.2.1 Iron and steel production

The iron and steel sector accounts for approximately 7% of the global GHG emissions and 11% of the global CO_2 emissions. Steel production emits approximately **2.2 tonnes CO_2eq per tonne of steel** (including direct and indirect emissions), amounting to total emissions of around 4.1 billion tonnes CO_2eq from the global steel production of 1,886 Mt in 2024. (Worldsteel Association, 2025)

Production is expected to continue rising driven by increasing demand from developing countries, with the global steel production having already doubled between 2000 and 2020 (Hasanbeigi, 2022).

There are four routes for the production of steel, which involve several complex processes as illustrated in Table 5: BF-BOF (Basic Oxygen Furnace) route, direct smelting of scrap, also called EAF, smelting reduction, and direct reduction (European Bureau for Research on Industrial Transformation and Emissions, n.d.). The production can take place in integrated steel works. The steps of a production route typically include coke production, sintering, pelletising, BF, and steelmaking using BOF, open hearth furnaces (OHFs) or in independent facilities specialising in specific processes.

The challenge lies in correctly establishing the system boundaries and distinguishing between facility types and production routes to ensure accurate emission allocation. The GHG emissions from production processes must be attributed to their respective facilities and accounted for appropriately to avoid double counting or omission.

According to 2024 data from the World Steel Association, approximately 70.4 % of the global steel production utilised the BF-BOF route, while EAFs accounted for 29.1 % (Worldsteel Association, 2025). Secondary steelmaking facilities produce steel predominantly from recycled steel scrap using EAFs, which is generally less carbon-intensive due to its reliance on recycled materials.

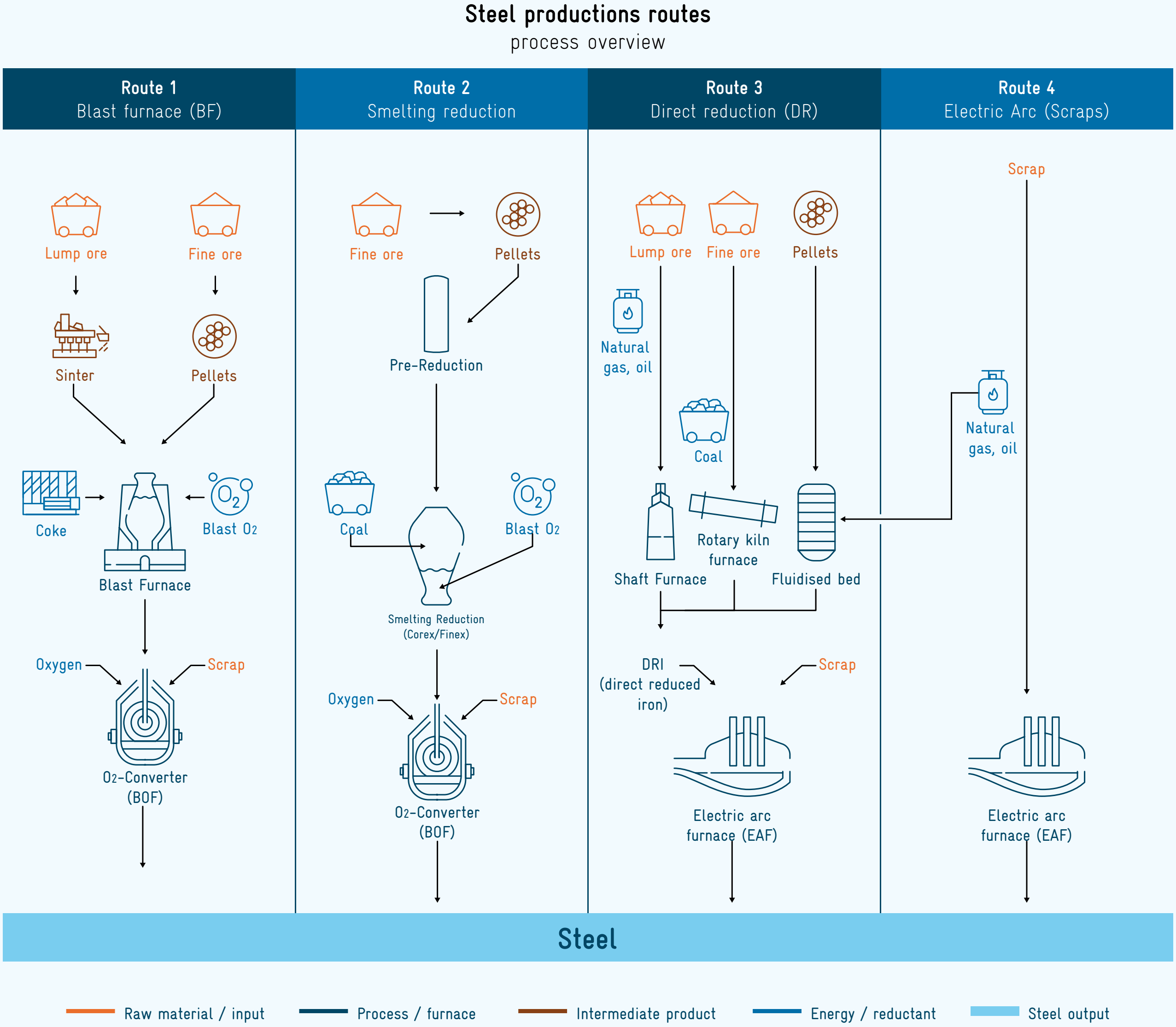
According to the 2006 IPCC Guidelines, Volume 3, iron and steel production generates emissions from chemical reactions and from combustion of fuels (IPCC, 2006d). The main sources include:

- Metallurgical coke is produced by heating coal to produce coke which generates coke oven gas. Coke serves as both fuel and chemical reductant, facilitating the reduction of iron ore to molten iron.
- Sinter and pellet production processes prepare iron ore for BF using carbon-containing fuels (coke breeze, natural gas, coal, or coke oven gas), with emissions depending on the fuel type and carbon content.

- BF iron making is the largest CO_2 source in integrated steelmaking, where metallurgical coke reduces iron ore to molten iron through chemical reactions and combustion.
- In steelmaking processes, EAF generate CO_2 primarily from carbon electrodes and carbon sources added to the steel melt.
- While direct emissions from casting and rolling are relatively minor compared to earlier stages, fuel combustion for heating and shaping steel contributes to the facility's overall emissions.
- BF and coke oven gases are often recovered and used as fuel sources on-site or off-site, contributing to the overall facility CO_2 and CH_4 emissions.

For integrated plants, by-product gases are sometimes transferred between coke production and iron and steelmaking. These gases include coke oven gas or BF gas. Emissions are allocated based on where the carbon is consumed. If the gas is used as a reductant or chemical input in iron and steelmaking, emissions are reported under IPPU. If combusted for energy outside the process boundary, emissions are reported under Energy.

Figure 9: Main processes of crude steel production process[27]



27 Own adaptation from: European Bureau for Research on Industrial Transformation and Emissions (n.d.).

Box 9. Sustainable transition of the iron and steel industry

The steel industry is undergoing a transition toward decarbonisation. Over 70% of the world's BF will need reinvestment by 2030, and this presents a major opportunity for change. Low-carbon technologies are advancing rapidly, including hydrogen-based direct reduced iron (H_2-DRI), renewable-powered EAFs, and CCUS solutions. These innovations depend on access to clean electricity, affordable green hydrogen, and supportive infrastructure.

The transition includes three phases: a short-term focus on efficiency and electrification, a medium-term phase of scaling up technologies like H_2-DRI and carbon capture, and a long-term outlook for emerging technologies such as molten oxide electrolysis. This presents a chance to avoid locking in high-carbon assets and to shift toward a sustainable future for steel production. MRV provides the necessary data to include carbon pricing, CBAM, and other policies into the investment decision.

Choice of method

The 2006 IPCC Guidelines offer different ways to calculate emissions from making metallurgical coke, iron and steel. They use a three-tier framework for CO_2 emissions and a two-tier framework for CH_4 emissions.

There are two main ways to perform the calculations. The input-based approach looks at the carbon in the raw materials and other substances used in production. The production-based approach multiplies how much is produced nationally by default EFs.

Tier 1 works well when only national production statistics are available. It is suitable with no detailed information about raw materials, production processes, or how facilities are set up. However, this method might overestimate or underestimate emissions. This is particularly true in countries with unusual industrial setups (for example, with many electric arc furnaces) or different ways of managing by-products.

The emissions for iron and steel production are calculated by applying process-specific default EFs to national production volumes. This covers the three main steelmaking processes: BOF, EAF, and OHF. If the data by processes is not available, it is possible to use global averages to split total steel production (65% BOF, 30% EAF, 5% OHF). The method also covers pig iron that is not converted for steel, DRI, sinter, and pellet production. Each has separate formulas. The 2006 IPCC Guidelines also include CH_4 emission calculations for iron and steel processes. These simplified assumptions should only be used when more detailed process information is not available as they may not accurately reflect each country's specific situation. Table 9 explains the step-by-step calculations for both CO_2 and CH_4 emissions from sinter production or iron production.

TIER 1

Tier 1 only needs basic national production data. This includes steel produced by each process type, total pig iron not made into steel, and total coke, DRI, pellets, and sinter produced. For steel, total crude steel production includes usable ingots, continuously cast semi-finished products, and liquid steel for castings. For coke, Tier 1 assumes all production happens in integrated facilities. Default EFs from the 2006 IPCC Guidelines are used for each process.

For EAF steelmaking, the default EF excludes emissions from iron production. In contrast, the BOF and OHF factors include emissions from BF iron production.

It is good practice to report steel production broken down by process with the corresponding default EFs. The amount of iron not processed into steel should also be included. Early involvement of important industrial trade associations in the GHG accounting process is recommended for national GHG inventory compilers. This supports reviewing methods and data, ensuring completeness and transparency.

Table 11: Calculation of CO_2 emissions from iron and steel production using Tier 1 method

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 1a	Compile steel production shares by process type	Sum national steel production by steelmaking process	• BOF steel (tonnes) • EAF steel (tonnes) • OHF steel (tonnes)	• Governmental agencies responsible for manufacturing statistics • Business or industry trade associations • Individual iron and steel companies	• Verify that the sum of disaggregated data matches the official national industry statistics; resolve unit inconsistencies. • Verify that BOF/EAF/OHF shares reflect the reporting year and national circumstances; document sources.
Step 1b	Compile steel production shares by process type	If only aggregate production data is available, a weighted factor should be used	Global Average Factor (65% BOF, 30% EAF, 5% OHF) (tonne CO_2 per tonne of steel produced)	IPCC default value	Document use of the default split (65% BOF, 30% EAF, 5% OHF) and justify applicability to your country and year.
Step 2	Compile pig iron production not processed into steel	Identify quantity of pig iron not converted to steel	Pig iron production not processed into steel (IP, tonnes)	• Governmental agencies responsible for manufacturing statistics • Business or industry trade associations • Individual iron and steel companies	Confirm that BOF/OHF CO_2 EFs already include blast furnace iron making; ensure pig iron not converted to steel is not double-counted.
Step 3	Compile DRI, sinter, and pellet production	Sum national production separately for each of the products DRI, sinter, and pellet	• DRI produced (tonnes) • Sinter produced (SI, tonnes) • Pellet produced (P, tonnes)	• Governmental agencies responsible for manufacturing statistics • Business or industry trade associations • Individual iron and steel companies	• Completeness: ensure all processes (DRI, sinter, pellet) are included; • check for offsite production flows.
Step 4 (CO_2)	Apply default EFs for steel production	CO_2 = (BOF × EF_BOF) + (EAF × EF_EAF) + (OHF × EF_OHF)	Default Tier 1 EFs: • EF_BOF = 1.46 t CO_2/t steel • EF_EAF = 0.08 t CO_2/t steel • EF_OHF = 1.72 t CO_2/t steel	IPCC default values	• Confirm applicability: EAF EF (0.08 t CO_2/t) is valid only for scrap-based EAF; • do not apply to EAFs using pig iron

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 5 (CO_2)	Apply default EFs for pig iron, DRI, sinter, and pellet	• CO_2 = (IP × EF_IP) • CO_2 = (DRI × EF_DRI) • CO_2 = (SI × EF_SI) • CO_2 = (P × EF_P)	Default Tier 1 EFs: • EF_IP = 1.35 t CO_2/t pig iron • EF_DRI = 0.70 t CO_2/t DRI • EF_SI = 0.20 t CO_2/t sinter • EF_P = 0.03 t CO_2/t pellet	IPCC default values	• Validate assumptions: DRI default EF assumes natural gas as primary fuel. • Check completeness: all relevant production quantities present and units consistent.
Step 6 (CO_2)	Calculate total CO_2 emissions	Total CO_2 = Sum of emissions from Steps 4 and 5			
Step 7 (CH_4)	Apply default EFs for CH_4 for Apply default EFs for CH_4 for • iron produced nationally including iron converted to steel and not converted to steel, • DRI, • sinter	• CH_4 = (PI × EF_PI) • CH_4 = (DRI × EF_DRI) • CH_4 = (SI × EF_SI)	Default Tier 1 EFs: • EF_DRI = 1 kg CH_4/TJ on a net calorific basis • EF_SI = 0.07 kg CH_4/kg sinter	IPCC default values	Note that CH_4 from steel-making processes is assumed negligible in Tier 1.
Step 8 (CH_4)	Calculate total CH_4 emissions	Total CH_4 = Sum of emissions from Step 2			• Document factors used, units, and any conversions; record uncertainty qualitatively.
Step 9	Report and document	Provide assumptions, EFs, and data sources used			Report the total steel production by process and corresponding EFs used and to report the amount of iron produced that is not processed into steel.

TIER 2

Tier 2 methodology uses actual national data on inputs and outputs of processes. It uses a material balance approach for the actual quantities of raw materials and other substances consumed in production processes.

The Tier 2 method is based on the national data on the consumption of process materials for iron and steel production, sinter production, pellet production, and direct reduced iron production. Process materials include all carbon-containing materials used in iron and steel production such as reducing agents (e.g., coke, coal), carbonate fluxes (e.g., limestone, dolomite), process gases (e.g., BF gas, coke oven gas), and other carbon-containing materials (e.g., carbon electrodes). The calculation uses a mass balance approach, multiplying the quantities of these materials by their material-specific carbon contents. This method is not applicable for estimating the CH_4 emissions, for which only a Tier 1 and a Tier 3 approach are available.

While the 2006 IPCC Guidelines provide default carbon contents for materials such as BF gas, coal, coke, limestone, and natural gas under Tier 1, Tier 2 allows countries to develop more representative factors using process material data specific to their own country for both primary and secondary production processes. These are then multiplied by the appropriate carbon contents of process materials. The calculation steps are shown in Table 11.

To collect this comprehensive data, inventory compilers need to coordinate with industry companies, trade associations, or government agencies to obtain detailed information on material consumption and production processes.

It is good practice to document all emissions, activity data, EFs, and assumptions, and to clarify the linkage to the energy sector to avoid double counting. This documentation should be accessible to everyone involved in preparing the inventory.

Table 12: Calculation of CO_2 emissions from iron and steel production using Tier 2 method

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 1	Identify national iron and steel process streams to include: • sinter production • blast furnace iron production • DRI production, pellet production • and onsite/offsite production arrange-ments		• Process list; • facility types; integrated vs non-integrated; • onsite/offsite coke	• National statistics and energy statistics • Industry associations • Iron and steel companies	• Confirm complete-ness of facility list and process coverage (sinter, BF iron, DRI, pellet; onsite/offsite coke). • Cross-check against industry directories and regulator registers. • Document process configurations (integrated vs non-integrated) and reporting boundaries (IPPU vs Energy) to avoid omissions or overlaps

28 Implied emission intensity = Total CO_2 emissions ÷ Total production (e.g., tonnes CO_2/tonne steel). This calculated intensity should be compared to IPCC default values or prior years to verify plausibility.

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 2	Compile national consumption and production of process materials and gases for each process, distinguishing onsite/offsite flows where needed		For iron & steel, sinter, DRI, pellet: amounts of reducing agents and process materials including: • Coke breeze (CBR) • Coke oven gas (COG) • BF gas (BG) • Natural gas, fuel oil (PMa) • Limestone/dolomite • Metallurgical coke; coking coal • Off-site transfers (SOG, COG)	• Government manufacturing or energy stats • Industry trade associations • Plant/facility data (national aggregates)	• Reconcile units (tonnes, GJ, m3) and apply consistent conversion bases. • Investigate inconsistencies between plants for potential measurement differences vs genuine technology/operation differences.
Step 3	Assign material-specific carbon contents (defaults)		Carbon contents examples: • Coke 0.83 kg C/kg • Natural gas 0.73 kg C/kg • Limestone 0.12 kg C/kg • Dolomite 0.13 kg C/kg • Coke oven gas 0.83 kg C/kg • BF gas 0.17 kg C/kg	2006 IPCC Guidelines, Volume 3, Table 4.3	Ensure gas carbon contents match the reported basis (e.g., m3 at specified T/P; GJ on NCV basis) and are compatible with activity units.
Step 4	Calculate CO_2 for iron & steel production (mass balance)	• Iron & Steel (mass balance): E_CO_2,non-energy = ∑(inputs × Cx) − ∑(outputs × Cx) × 44/12 • Sinter: E_CO_2 = [CBR×C + COG×C + BG×C + ∑PMa×C − SOG×C] × 44/12 • DRI: E_CO_2 = 44/12 × [DRI_NG×C_NG + DRI_BZ×C_BZ + DRI_CK×C_CK]		Inputs and outputs by process with material-specific carbon contents	• Arithmetic checks: verify 44/12 conversion and that inputs/outputs use matching units and ensure carbon contents are from consistent sources. • Plausibility checks: compare implied emission intensities[27] against IPCC defaults or prior years; explain material shifts or efficiency changes.

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 5	Include pellet production (if applicable)	E_CO_2,pellet = 44/12 × ∑(fuel consumption × fuel carbon content)		Energy/fuel consumption data for pellet plants	Confirm fuel consumption, heating values, and carbon contents are on consistent bases; if inputs unknown, justify use of Tier 1 EF as fallback and document assumption.
Step 6	Sum national CO_2 totals	Aggregate CO_2 from sinter, iron, DRI, pellet production			Verify sum of process-level emissions equal national totals; confirm no double counting between processes or due to onsite/offsite transfers.
Step 7	Report and document	Provide assumptions, EFs, and data sources used			Document the estimated or calculated emissions, all activity data, and corresponding

Box 10.

Brazil applies a mixed-tier approach for the iron and steel sector GHG reporting. Tier 2 carbon balance for CO_2 emissions using comprehensive facility-level data are provided by the Instituto Aço Brasil (IABr), and Tier 1 default EFs are used for CH_4 and N_2O. Activity data are aggregated by process type, sourced from IABr, the government statistics, trade, and energy data. This ensures robust coverage and confidentiality. EFs are country-specific where possible. Brazil applies adaptive data management, adjusting its methodology based on data availability over time: detailed IABr data for 2007-2016, proportional scaling for 2017-2022 when detailed data became unavailable, while maintaining time series consistency. For multi-source verification, Brazil cross-validates data using multiple independent sources mentioned above to ensure reliability and identify discrepancies across different reporting systems.

TIER 3

This approach uses plant-specific data to capture the differences in technology, feedstock, and operational practices between individual facilities. It requires either direct measurements of emissions from each facility or detailed plant-level records of what goes into and comes out of processes.

Both metallurgical coke and iron and steel production follow the same fundamental Tier 3 structure. The Tier 3 method can be based on (a) plant-specific direct emissions monitoring data (for both CO_2 and CH_4), or (b) plant-specific mass balance approach, using facility-specific process material data and facility-specific carbon contents (for CO_2). When the CO_2 and CH_4 emissions are measured at the individual facilities, these data can be directly added together to account for national emissions. Otherwise, emissions can be calculated using plant-specific activity data. For the calculations, iron and steel facilities provide plant-specific data on individual reducing agents, exhaust gases, process materials, and products. This detailed approach accounts for the differences in production routes (BOF vs EAF), raw material quality, fuel mixes, and operational practices across facilities.

This method is resource-intensive. It requires extensive data collection systems, rigorous quality assurance protocols, and potentially legal agreements to handle confidential industrial data. It demands strong cooperation from industry and robust national data management systems.

It is a good practice to document the calculated emissions and all data sources, to protect facility-specific data, and to collect, compile, and aggregate facility-specific measured emissions or process material data, when using mass balance or direct monitoring approaches.

For Tier 2 and 3, it is a good practice to develop emissions estimates at the plant level because technologies can differ substantially (specifically, furnaces). The national GHG inventory compiler should ensure that each facility documents the EFs and carbon contents used, and that these reflect the specific processes and materials at the facility. The carbon contents and production or consumption mass rates for all process materials and off-site transfers should be adjusted to reflect plant-level variations from default values.

Box 11.

Türkiye applies a Tier 3 methodology for the CO_2 emissions from iron and steel as well as sinter production in integrated plants, while the CO_2 emissions from pellet production and the CH_4 emissions from sinter use Tier 1 methods. Activity data are collected through annual questionnaires and direct measurements at facilities, with energy balances and targeted surveys ensuring comprehensive coverage. For EFs, priority is given to collecting plant-specific carbon content data for integrated facilities. Default values are used where necessary, and laboratory analyses are employed to ensure accuracy. For EAFs, national-level data are combined with default carbon contents, and implied factors are used if data are missing. Collaboration with industry experts and transparent data management underpin Türkiye's robust inventory approach.

Kazakhstan reports the steel sector GHG emissions using plant-specific data from AO "Qarmet", the largest integrated steel and mining company in Kazakhstan, and from the Bureau of National Statistics. The CO_2 emissions are calculated based on changes in carbon content during steel production from pig iron, metallised pellets, and steel scrap, with a Tier 3 methodology applied for electric steelmaking. Activity data include specific consumption rates, carbon content parameters, and production volumes, supported by collaborative working group reviews. EFs combine plant-specific and default IPCC values, with explicit calculation of carbon released from electrode consumption for electric steelmaking.

Box 12. IPCC 2019 Refinement – Iron and Steel

The 2019 Refinement to the 2006 IPCC Guidelines introduced substantial updates to methodologies for the iron and steel sector. The revisions aim to improve the accuracy and consistency of emission estimates across different production routes and process types, while enhancing flexibility for countries with limited data availability. Key changes include:

Tier structure and methodology:

- New 5-tier structure for CO_2 emissions (Tier 1a, 1b, 2, 3a, 3b) replaces traditional 3-tier approach.
  - Tier 1a - production-based method with default EFs
  - Tier 1b (Hybrid): production data + default carbon contents for BFG/ Linz-Donawitz Gas (LDG)
  - Tier 2 - Carbon mass balance with national input-output data
  - Tier 3a - Hybrid approach (partial measurements + mass balance for unmeasured sources)
  - Tier 3b - Full measurements or verified modelling for all sources
- Hybrid approaches (e.g., Tier 1/Tier 2) permitted for non-key categories when country-specific data incomplete.
- New Equation 4.8a: explicit methodology for BFG and LDG flaring emissions.

EFs and data:

- Conservative default EFs adopted with flexibility for technology-specific adjustments when justified by national data.
- Comprehensive updated tables: 4.1 (coke), 4.1a (sinter/pellet), 4.1b (iron/steel), 4.2 (CH_4), 4.2b (N_2O).
- Coke production EFs distinguish by-product recovery; lower factors for advanced technologies (e.g., CDQ).
- Sinter/pellet/EAF factors reflect maximum reported values; sinter factors higher for carbonate ore use.
- Steelmaking EFs route-specific; EAF factor applies only to scrap-based steelmaking, excludes iron production.
- Updated CH_4 factors cover coke, sinter, pig iron, DRI; new N_2O factors for flaring.
- Default carbon contents (Table 4.3) for Tier 1b/2; country-specific values required for key categories, plant-specific data essential for Tier 3.

Process coverage:

- Systematic categorisation of coke production emissions (carbonisation, combustion, fugitive) with sector allocation guidance.
- New dedicated methodologies for CH_4 (sinter, pig iron, DRI) and N_2O (flaring).
- Enhanced QA/QC requirements for Tier 3 methods (measurement protocols, model verification).

Avoiding double counting

The 2019 Refinement provides detailed guidance on avoiding the double counting of emissions between the Energy and IPPU sectors for iron and steel production. It clarifies the reporting boundaries for integrated facilities and specifies the treatment of by-product gas use, flaring, and venting across sectors. Key provisions include:

- Clear boundaries are required to prevent the double counting between coke production (Energy sector) and steel production (IPPU sector), especially for integrated facilities.
- All combustion of by-product gases (BF gas, coke oven gas, converter gas) within steelworks (including sintering, steelmaking, rolling, coating, and internal electricity generation) are reported under IPPU.
- The combustion emissions from by-product gases exported off-site are reported under the appropriate Energy subcategory (e.g., 1A2f for other manufacturing, 1A1a for public electricity/heat).
- Flaring or venting of gases at coke ovens is reported under the Fugitives subcategory of Energy sector; similar activities at other steel plant locations are reported under IPPU.

Table 13: Calculation of CO_2 and CH_4 emissions from iron and steel production using Tier 3 method

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 1a	Classify facilities by data availability	For each iron and steel facility, determine: • Does facility have measured CO_2 and/or CH_4 emissions from continuous monitoring? • Does facility have plant-specific activity data (process materials consumed/produced) and facility-specific carbon contents? Create three lists: (A) Facilities with measured emissions (B) Facilities with mass balance data (C) Facilities with gaps (neither measured nor complete mass balance data available)	• Facility IDs and boundaries • Reporting period (year) • Reported CO_2, CH_4 (tonnes)	• Individual facility records • Regulatory emissions registries • Industry associations • Government manufacturing statistics agencies	• Confirm classification covers all national facilities • Document facility boundaries and reporting systems • Note any non-reporting sites
Step 2a	Collect measured emissions (for facilities in List A)	Retrieve the measured CO_2 and CH_4 for each facility (prefer plant total for iron & steel processes under IPPU)	CO_2_measured, plant (t/yr) CH_4 _measured, plant (t/yr)	• Plant continuous emissions monitoring systems (CEMS) • Verified annual emissions reports • Third-party verification reports	Check method and verification status; ensure period matches calendar year; reconcile units.

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 2b	Collect plant-specific mass balance data (for facilities in List B)		Activity data (process materials): • Coking coal consumed (tonnes) • Coke produced/consumed (tonnes) • Pig iron produced (tonnes) • Steel produced by type (BOF/EAF/OHF) (tonnes) • Limestone, dolomite consumed (tonnes) • Natural gas, fuel oil consumed (tonnes or m³) • • Blast furnace gas, coke oven gas consumed (m³) • • Sinter, pellets, DRI produced (tonnes) • • Off-site transfers (coke oven by-products, gases) (tonnes or m³) • • Facility-specific carbon contents: • • Carbon content of each material (kg C/kg or kg C/m³) • • Source of carbon content data (lab analysis, supplier data, plant records)	• Individual facility production records • Plant laboratory analyses • Supplier material specifications • Facility energy/material balance reports • Industry trade associations	• Verify carbon contents are facility-specific, not defaults • Check consistency of material flows (mass balance closure) • Compare facility-specific carbon contents to IPCC Table defaults; document and explain differences • Ensure activity data period matches calendar year • Verify units consistency

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 3a	Calculate emissions for mass balance facilities (List B)	Apply Tier 2 equations at plant level using: • Plant-specific activity data (from Step 2b) • Facility-specific carbon contents (from Step 2b) Calculate for each facility: CO_2_calculated,plant = ∑[(Material_consumed × C_content) − (Material_produced × C_content)] × (44/12) For CH_4: If plant-specific CH_4 EFs are available, apply to plant-specific production data. Key distinction from Tier 2: Use facility-specific carbon contents, not national defaults.		• Tier 2 equations from the 2006 IPCC Guidelines • Facility-specific data from Step 2b	• Verify facility-specific carbon contents are documented • Compare calculated emissions to industry benchmarks for similar facilities • Document where facility-specific values differ from IPCC defaults and explain why (e.g., coal quality, process configuration)

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 3b	Address data gaps (for facilities in List C)	For facilities without measured emissions OR complete mass balance data: Option 1 (preferred): Collect missing data through facility engagement Option 2: If data cannot be obtained: • Use Tier 2 approach with national-level data for that facility • Document as a gap/limitation • Flag for improvement in next inventory cycle		• Direct facility contact • Industry association support • Regulatory data requests	• Maintain transparent gap list • Document reasons for data unavailability • Track improvement plan for future cycles
Step 4	Check scope and allocation	For each facility (Lists A, B, and C), verify: Ensure reported emissions corresponds to IPPU process emissions for iron & steel (not Energy Sector combustion outside the process boundary); exclude coke production reported under Energy.	Boundary/attribution notes per facility	Plant boundary documentation; regulator guidance	Avoid double counting with Energy Sector (e.g., coke production). Document inclusions/exclusions

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step5	Examine consistency between facilities	Review data from different facilities to identify: • Inconsistencies in reported emissions or carbon contents • Variations in measurement techniques • Real differences due to operational conditions or technology Specific checks: • Compare plant-specific carbon contents across facilities • Compare emission intensities (CO_2/tonne steel) across similar facilities • Investigate outliers Determine whether inconsistencies reflect: (a) Errors → correct (b) Different measurement methods → document (c) Real operational differences → document and explain		• Aggregated facility data from Steps 2a, 2b, 3a • Industry benchmarks • Technical literature on iron & steel processes	• Document investigation of inconsistencies • Explain variations in carbon contents or EFs • Compare aggregated plant-level estimates to industry totals for process materials consumption (where trade data available) • Ensure high measurement standards are documented

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
Step 6	Aggregate to national total	Sum emissions across all facilities: National CO_2 = ∑(CO_2_meas-ured,plant) + ∑(CO_2_calculat-ed,plant) + CO_2_gap facilities National CH_4 = ∑(CH_4_meas-ured,plant) + ∑(CH_4_calculat-ed,plant) + CH_4_gap facilities Maintain disaggregation by: • Facility • Calculation method (measured vs. calculated) • Process type (coke, sinter, blast furnace, BOF, EAF, etc.)	• National CO_2 = ∑ CO_2_meas-ured,plant • National CH_4 = ∑ CH_4_meas-ured,plant	• Aggregation worksheet; Facility-level results from Steps 2a, 3a, 3b	• Spot-check arithmetic; ensure no plant is counted twice. • Compare aggregated national emissions with previous years and industry benchmarks to check reasonableness. Document where facility-spe-cific carbon contents differ from IPCC defaults and explain why (e.g., different coal quality, process configu-ration).
Step 7	Report and document	Provide summary, and data sources used			Document the calculated emissions and source of all data, taking into account the need to protect the confidential-ity of data for specific facilities if the data are business-sensi-tive or of a proprietary nature.

3.2.2 Ferroalloy production

Concentrated alloys of iron with one or more metals, including silicon, manganese, chromium, molybdenum, vanadium, and tungsten, are known as ferroalloys. They are produced mainly in EAFs using carbonaceous reductants. These reductants include coal, coke, charcoal, and wood. These alloys are essential for deoxidising and modifying steel properties. Silicon metal is also used in aluminium alloys, silicones, and electronics.

The main GHG produced is CO_2. Smaller contributions come from CH_4 and N_2O for certain alloy types. Emissions arise from reduction of metal oxides, electrode consumption, and calcination of carbonate fluxes[29]. Covered arc furnaces emit mostly carbon monoxide (CO). This CO is assumed to be converted to CO_2 either in-plant or in the atmosphere.

Table 14: Overview of methodological Tiers in ferroalloy production

Tier	What to calculate	Key inputs	Parameters
Tier 1	Estimate CO_2 and CH_4 from ferroalloy production using default EFs per tonne of ferroalloy by type.	• National ferroalloy production by type (FeSi, FeMn, SiMn, FeCr, etc.) • Default EF per ferroalloy type	• Governmental agencies responsible for manufacturing statistics • Business or industry trade associations • Individual ferroalloy companies
Tier 2	Estimate CO_2 from ferroalloy production using default EFs per for the reducing agents and the carbon content of raw materials such as ore, slag, product. For CH_4 the calculation method is based on operation-specific EFs.	• Mass of reducing agents by type • Default carbon contents per material • Ores and slag formers • Production by ferroalloy type	• Government manufacturing/ energy statistics • Industry association data • IPCC default carbon content tables
Tier 3	Estimate CO_2 based on amount and analyses based on percentage of ash and volatiles of reducing agents	• Mass and plant-specific carbon content of: –Reducing agents –Ores –Slag forming materials –Products (ferroalloy) –Non-product streams (dust, off-gas) • Calculated per ferroalloy type	• Facility-specific emissions data directly from companies • Plant-level laboratory analyses • Periodic compositional testing • Aggregation to national totals for reporting

For Tier 1, it is good practice to use default EFs when only national production statistics are available and report total ferroalloy production by process and corresponding EFs used.

For Tier 2 it is a good practice to document all estimated emissions, activity data, EFs, and assumptions, as well as to clarify the linkage with the fuel combustion which is accounted in the Energy sector to avoid double counting.

29 Carbonate fluxes are minerals such as limestone or dolomite added to the furnace charge to control slag chemistry, remove impurities, and adjust the basicity of the melt.

30 The choice of EFs depends on the operation of the furnace. It can be batch-charging, sprinkle-charging, or sprinkle-charging and above 750 degrees Celsius.

For Tier 3, it is a good practice is to document calculated emissions and all data sources, and to protect facility confidentiality, as well as to ensure QA/QC procedures are in place.

3.2.3 Primary aluminium production

Primary aluminium is produced exclusively by the Hall-Héroult electrolytic process. This process uses carbon anodes to convert alumina from bauxite into aluminium metal which releases CO_2. Primary production results in much higher GHG emissions than secondary production from recycled scrap. These emissions mainly come from the energy-intensive process. Calculating these emissions requires accurate data on the anode consumption and carbon content. Production data must distinguish between Søderberg and Prebake cell technologies. No further breakdown of production technologies is needed.

During primary aluminium production, alumina is dissolved in a molten salt bath. Electricity is used to separate the aluminium metal. Normally, the carbon anode (Prebaked anodes in Prebake cells or anode paste in Söderberg cells) is consumed and releases CO_2. However, if the amount of alumina in the bath falls below a certain level, the cell voltage rises. This reaction is called an "anode effect". It leads to the generation of perfluorocarbons (PFCs). These include carbon tetrafluoride (CF_4) and hexafluoroethane (C_2F_6). These gases have much higher global warming potential than CO_2. They are only released during anode effects, so when the process no longer runs normally. Anode effects are unique to primary aluminium production. They can make a significant contribution to the sector's total GHG emissions.

Box 13.

Kazakhstan estimates the CO_2 emissions from ferroalloy production using a Tier 2 method based on the plant-reported reductant use (Kazchrome) and the national statistics. CO_2 is calculated with a coke-based emission factor of 3.3 t CO_2 per tonne of reductant. Activity data come from Kazchrome and the National Statistics Bureau. From 2022, data from the new Saryarka ferroalloy plant (ASIA FerroAlloys) with recalculations are included.

Table 15: Overview methodological Tiers in aluminium production

Tier	What to calculate	Key inputs	Parameters
Tier 1 (CO_2)	Estimate CO_2 from primary aluminium production using default EFs per tonne of aluminium by technology type (Prebake or Söderberg).	• National aluminium production by technology type (Prebake/Söderberg) in tonnes Al • Default EFs per technology type	• Governmental agencies responsible for manufacturing statistics • National aluminium associations or International Aluminium Institute • Individual aluminium companies or industry groups
Tier 1 (PFCs)	Estimate CF_4 and C_2F_6 emissions using default EFs per tonne of aluminium by cell technology type (CWPB, SWPB, VSS, HSS).	• Production by cell technology type (CWPB, SWPB, VSS, HSS) • Default EF for CF_4 • Default EF for C_2F_6	

Tier	What to calculate	Key inputs	Parameters
Tier 2 (CO_2)	Estimate CO_2 from aluminium production using a mass balance approach based on net anode/ paste consumption with default values for anode impurities (sulphur, ash, hydrogen content).	• Metal production by technology type (tonnes Al) • Net anode consumption (Prebake) or paste consumption (Söderberg) per tonne Al • Default values for sulphur, ash, and hydrogen content in anodes/ paste • Carbon in dust (for Söderberg cells)	• Individual aluminium companies • Industry trade associations • Government manufacturing/ energy statistics • IPCC default composition tables • Plant-level process control systems (for anode effect data) • Production-weighted average of monthly anode effect data • IAI measurement data
Tier 2 (PFC)	Estimate CF_4 and C_2F_6 using technology-specific slope coefficients (based on anode effect minutes per cell day) or overvoltage coefficients.	• Anode effect minutes per cell day OR anode effect overvoltage (AEO) • Technology-specific slope or overvoltage coefficients • Weight fraction C_2F_6/CF_4 by technology	
Tier 3 (CO_2)	Estimate CO_2 based on mass balance using facility-specific carbon consumption and composition data for all anode materials (actual sulphur, ash, hydrogen content).	• Metal production per facility (tonnes Al) • Net anode/paste consumption per facility • Facility-specific composition data: –Carbon content –Sulphur content –Ash content –Hydrogen content • Carbon in dust and other streams	• Facility-specific emissions data directly from aluminium smelters • Plant-level laboratory analyses of anode materials • Periodic compositional testing at individual facilities • Continuous or periodic PFC measurements consistent with IAI GHG Protocol and established measurement practices • Aggregation to national totals for reporting
Tier 3 (PFC)	Estimate CF_4 and C_2F_6 using facility-specific slope or overvoltage coefficients derived from periodic or continuous PFC measurements at individual facilities.	• Anode effect minutes per cell day OR anode effect overvoltage per facility • Facility-specific PFC coefficients from direct measurements • Relationship between anode effect performance and measured PFC emissions	

It is considered a good practice to use accurate, facility-level data on anode effect minutes or overvoltage for all cell types. The production-weighted average of the monthly anode effect data should serve as the foundation for annual statistics. Consulting with aluminium companies or industry groups to ensure data availability and consistency is advised.

For high-performing facilities (with very low anode effect frequency or overvoltage), Tier 3 may not substantially improve accuracy over Tier 2 with regards to PFCs. In such cases, it is beneficial to identify these facilities annually to prioritise resources.

Box 14.

Brazil estimates the CO_2 and PFC emissions from primary aluminium production using mixed-tier approaches. For the CO_2 from anode/paste consumption, plants apply Tier 1–3 depending on technology and data availability: Tier 1 uses IPCC defaults by technology, Tier 2 applies carbon-balance equations with impurity corrections, and Tier 3 replaces defaults with plant-measured parameters. For PFCs (CF_4, C_2F_6), Tier 1 uses default EFs by cell technology; Tier 2 applies the slope method with C_2F_6 as a fraction of CF_4; Tier 3 uses plant-specific slope coefficients and ratios.

Activity data is derived from plant records and measurements (1990–2007/08), covering the aluminium output, anode/paste consumption, and anode-effect minutes/frequency for Novelis, Alcoa, Votorantim Metais–CBA, Albras, and Alumar (Valesul used Tier 1 for PFCs). From 2008 onwards, the production data by technology and plant is sourced from the Brazilian Aluminium Association (ABAL) and company reports (ALBRAS; CBA). Where detailed plant calculations ceased after 2007/08, Brazil held the CO_2 plant-specific factors at 2007 levels, averaged the last three CF_4 factors per plant, and fixed C_2F_6/CF_4 ratios at 2007 levels. Technologies distinguished include Soderberg (VSS, HSS) and Prebaked anode (CWPB, SWPB), with the inventory assigning the highest feasible tier by plant and period.

Box 15. IPCC Refinement 2019 – Primary Aluminium Production

The 2019 Refinement updates and expands the 2006 IPCC Guidelines for estimating the GHG emissions from primary aluminium production. The revisions strengthen methodological consistency across refining and smelting processes and provide more detailed, technology-specific approaches for PFC emissions and alternative alumina refining routes. Key methodological updates include:

- New guidance on accounting of the GHG emissions from alumina production via alternative refining processes: Bayer-sintering parallel, Bayer-sintering sequential and Nepheline processing processes.
- Updated guidance for PFC emissions, covering both high voltage anode effects and low voltage anode effects.
- Introduction of new technology classes (e.g., Point-Fed Prebake variants) for PFC accounting, replacing earlier classifications for this purpose.
- Updates for technology-specific default EFs for Tier 1 and Tier 2, and new methods (Tier 2b, Tier 3b) using individual anode effect durations.
- Introduction of facility-specific coefficients and measurement protocols for Tier 3, with new guidance on good measurement practices to improve accuracy.
- Recommendations on fully automated anode effect intervention strategies for reducing PFC emissions in modern smelters.
- Encouragements for separate and transparent reporting of CF_4 and C_2F_6 emissions, and clear documentation of all methods and data sources.
- Improved decision trees and criteria for method selection, including hybrid and updated approaches based on data availability and facility performance.

3.2.4 Magnesium, lead, and zinc production

Magnesium, lead, and zinc are key non-ferrous metals. They have distinct GHG profiles and calculation challenges. Magnesium production can use electrolysis or thermal reduction. It is unique for its significant use of cover gases in casting. These cover gases include sulphur hexafluoride (SF_6) or hydrofluorocarbons (HFCs), potent GHGs. Lead is produced from both primary ores and secondary (recycled) materials, mainly emitting CO_2. Secondary production is generally less emission-intensive. Zinc production can follow electrolytic or thermal routes. The thermal route is more CO_2-intensive due to the use of carbon reductants.

Table 16: Overview methodological Tiers in magnesium, lead, and zinc production

Tier	What to calculate	Key inputs	Parameters
Tier 1 (CO_2)	**Magnesium:** Estimate CO_2 from primary production using default EFs by ore type (dolomite or magnesite). Estimate SF_6 (or alternative cover gases) from casting/handling based on default consumption rates. **Lead:** Estimate CO_2 using default EFs by production type (primary blast furnace, primary direct smelting, secondary). **Zinc:** Estimate CO_2 using default EFs by process type (Waelz Kiln, Imperial Smelting Furnace, or electro-thermic).	**Magnesium:** • Primary production by ore type (dolomite/magnesite) in tonnes • Default CO_2 EF for dolomite and magnesite • Magnesium casting/handling quantity • SF_6 (or alternative cover gas) consumption **Lead:** • Total lead production (tonnes) • Default EFs by process type **Zinc:** • Zinc production by process (tonnes) • Default EFs	• Government manufacturing statistics • National industry associations • Trade associations • Production capacity data (verification) • Cover gas supplier records (magnesium) • Industry trade organisations
Tier 2	**Magnesium:** Estimate CO_2 using company/plant-specific EFs for primary production. Estimate cover gas emissions using technology-specific consumption rates. **Lead:** Estimate CO_2 based on total amounts of reducing agents and process materials with default carbon contents, adjusted for furnace type. **Zinc:** Estimate CO_2 based on country-specific EFs calculated from total reducing agents and carbon-containing materials.	**Magnesium:** • Plant-specific production data • Company/plant-specific CO_2 EF • Type and amount of cover gas used • Technology-specific cover gas consumption rates **Lead:** • Production by furnace type and source (primary/secondary) • Total reducing agents (coke, coal, etc.) • Default carbon contents per material **Zinc:** • Production by process type • Total reducing agents consumed • Default carbon contents • Process-specific parameters	• Plant-level production records • Company-specific EFs • Government energy/manufacturing statistics • Business/industry trade associations • Individual company data • IPCC default carbon content tables

Tier	What to calculate	Key inputs	Parameters
Tier 3	**For all categories:** Use actual measured emissions from individual facilities (direct measurement) if available in an aggregated form. **For lead:** if direct measurements are not available, calculate CO_2 from plant-specific data on reducing agents and process materials with facility-specific carbon contents, aggregated by furnace technology.	Measured CO_2 emissions per facility **Lead:** • Plant-specific mass and carbon content of: –Reducing agents –Process materials –Off-site transfers • Furnace technology per plant	• Direct facility measurements • Facility-specific emissions monitoring • Plant-level laboratory analyses • Individual company detailed records • Periodic compositional testing • Data aggregated from individual facilities to national level • Governmental agencies (aggregation)

For magnesium, lead, and zinc, the 2006 IPCC Guidelines recommend at least Tier 2 methods. Tier 1 default factors may not reflect national technology or process differences.

It is good practice to use plant- or process-specific data. EFs should be adjusted for local conditions. Completeness should be ensured by including all production, both sold and used on-site.

For magnesium, it is essential to accurately report the type and amount of cover gas used. For lead and zinc, distinguishing between primary and secondary production improves accuracy. Distinguishing between electrolytic and thermal processes also improves accuracy.

To avoid double counting, it is important to ensure that the emissions from lead and zinc production (from reducing agents such as coke and coal) are not counted in both IPPU and Energy sectors. For magnesium, double counting CO_2 from carbonate calcination with emissions reported under "Other Process Uses of Carbonates" (Chapter 2) needs to be avoided.

Box 16.

Chile estimates the CO_2 emissions from secondary lead production using a Tier 2 carbon-balance method. Activity data (2007–2020) come directly from the country's single lead recycling plant, covering quantities of reductants and acid-neutralising materials. Reported CO_2e totals rose to 6.4 kt in 2020, up 18% since 2018, driven by increased battery recycling under Chile's Extended Producer Responsibility law.

EFs are plant-specific carbon contents for each reductant, reported by the operator and applied in a material balance with IPCC stoichiometry (44/12). The carbon content of the acid neutraliser is estimated theoretically by stoichiometry.

The inventory treats lead production as secondary (recycling of lead–acid batteries) since 2007, with CO_2 arising from reductant use in melting/fuming processes (e.g., coal, natural gas, metallurgical coke, petroleum coke in electric resistance furnaces). Time-series consistency (1990–2020) is maintained by using the same data source and carbon contents across years. Confidential plant data are not published.

3.3 Chemical industry

The chemical industry is one of the largest and most diversified industrial sectors globally. It produces a vast range of substances that are fundamental to modern economies. Its products are essential inputs for numerous other industries, such as agriculture, pharmaceuticals, construction, and manufacturing.

Globally, the chemical sector is the third-largest industrial source of CO_2 emissions. It is also the largest industrial energy consumer (IEA, 2023b). According to the Net Zero Industry Tracker 2024 from the World Economic Forum, absolute emissions for primary chemicals[31] have seen a 6% rise in the 2019–2023 period. This was driven by an increase in demand for ammonia (World Economic Forum, 2024b).

This sector is a significant contributor to national emissions. Emissions arise directly from chemical reactions or from the non-energy use of feedstocks. Additional emissions come from fuel combustion to generate electricity, heat or power.

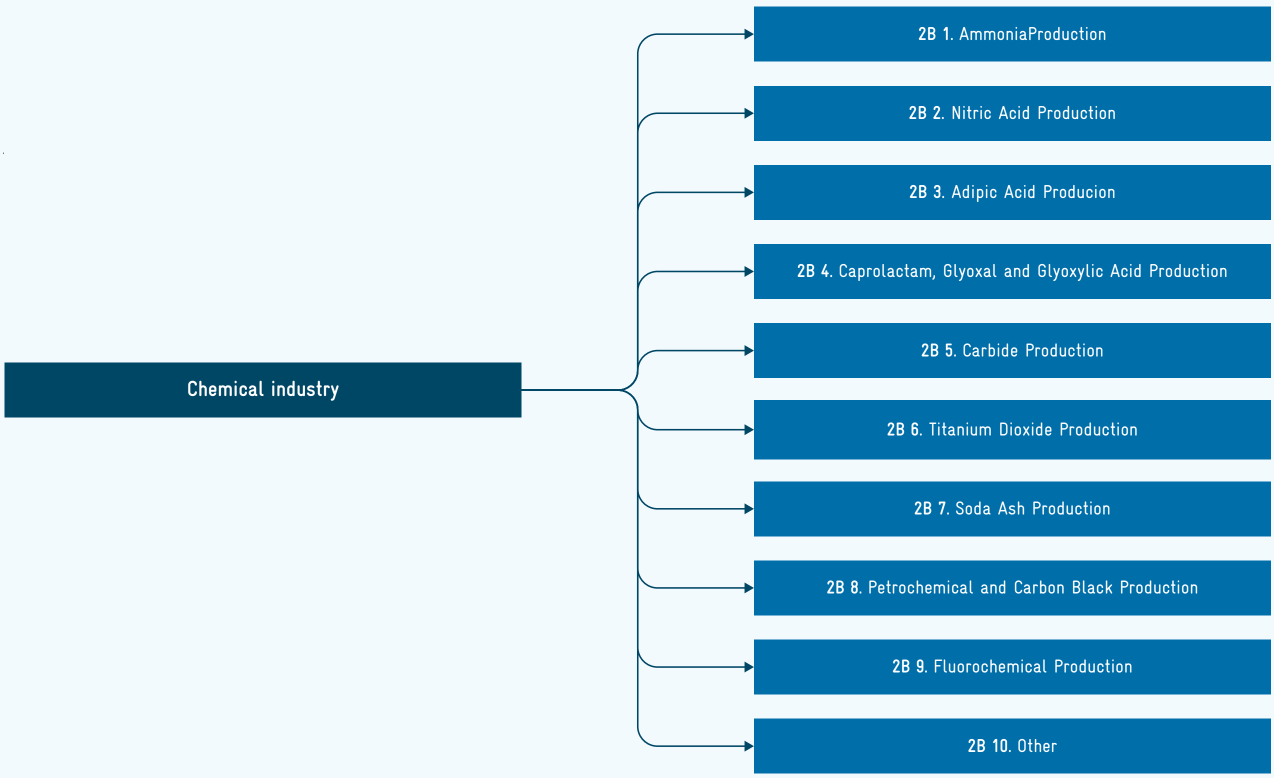
The 2006 IPCC Guidelines devise the subcategories in Figure 10 for the chemical industry, based on its products.

Relationship to the energy sector

A critical aspect are the fossil fuels used by the chemical industry in two distinct ways:

- As a fuel to generate heat, steam, or electricity. Emissions from this use should be reported under the Energy Sector.
- As a feedstock (a raw material) that is chemically transformed into a new product. The carbon from the feedstock can be stored in the final product or released as a process emission. These non-energy uses are then accounted for under the IPPU sector.

Figure 10: IPCC Categories under chemical industry



31 Chemicals produced from raw feedstocks that are subsequently converted into other chemicals in production routes.

To prevent double counting with the Energy sector in the national GHG inventory compilation, it is essential to subtract the amount of fossil fuel used as feedstock from the national energy consumption data.

3.3.1 Ammonia production

Ammonia (NH_3) is one of the most widely produced chemicals in the world. About 70% (IEA, 2021) of it is used to manufacture nitrogen-based fertilisers for agricultural use, such as urea and ammonium nitrate. NH_3 is a vital component of nitric acid, explosives, and refrigerants. It also acts as a precursor for various organic compounds, including amines and synthetic fibres. The production of NH_3 is a significant non-energy industrial source of CO_2 emissions. Around 2.4 tonnes of CO_2 are released per tonne of NH_3 production, amounting to direct emissions of 450 Mt worldwide (IEA, 2021).

The production of NH_3 is an energy-intensive process. It involves the reaction of nitrogen, obtained from air, with hydrogen. Most plants use natural gas (methane) for hydrogen production. However, it can also be produced from other hydrocarbons (as coal and oil) or via electrolysis from water.

The primary GHG emitted during the NH_3 production process is CO_2. It must be removed from the process gas before the final NH_3 synthesis step. This is typically done by scrubbing with a chemical or physical solvent. The solvent is then regenerated through heating, which releases a stream of almost pure CO_2. The latter may be captured and either used downstream (CCU) or stored (CCS). Most often, it is used as a feedstock for urea production. In urea manufacturing, the CO_2 reacts with NH_3, and the carbon is stored in the urea product. Emissions from the later use of urea are accounted for in the sectors where it is used, e.g. AFOLU. The captured CO_2 can also be purified and liquefied to produce liquid carbonic acid. This is sold for use in other industries, most notably for carbonating beverages.

Choice of method

According to the 2006 IPCC Guidelines, the CO_2 emissions from ammonia production are estimated based on the amount of fuel used as feedstock for the production processes. Emissions from the conversion of the process input (e.g. natural gas) are considered process emissions, even though a share of the process input might be used for combustion purposes. CO_2 emissions are straightforward and need to be reported as per 2006 IPCC Guidelines. Completeness can be improved by including the emissions of any fugitive CH_4. These may come either from the primary reformer stage or catalytic methanation of the CO_2 process.

The choice of the calculation method depends on the availability of plant-specific data. This is illustrated in the decision tree in Figure 3.1 of the 2006 IPCC Guidelines.

TIER 1

This method is the simplest approach and uses the national ammonia production data obtained from the national statistics. In their absence, production capacity data can be used. The 2006 IPCC Guidelines provide default values for the requirements for fuel as feedstock, EFs, carbon content factor (CCF) and carbon oxidation factor (COF). The CO_2 recovered in urea production can be estimated from the amount of urea produced.

If no data on fuel type or process type are available, it is good practice to use the highest EF. This ensures a conservative estimate. If a deduction is made for the CO_2 used in urea production, it is important to include the emissions from the urea use within the respective sector. If data on urea production are not available, it is good practice to assume that the CO_2 recovered is zero.

When the activity data is based on capacity to determine ammonia production, it is good practice to multiply the ammonia production capacity by a utilisation factor of 80%. A variability of ±10% (i.e., between 70% and 90%) is accepted. This approach helps account for any real-world operational fluctuations. In the absence of specific data, it is good practice to use the highest total fuel requirement per tonne of ammonia. This maintains a conservative estimate. For processes involving partial oxidation, if no information on the fuel type is available, the average of the provided values should be used to derive the EF.

Table 17: Calculation of CO_2 emissions from ammonia production using Tier 1 method

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
1	Compile ammonia production	If production data are not available, production capacity can be used	AP: ammonia production	• National statistics	• Confirm totals align with official industry statistics. • Reconcile units.
2	Compile urea production (for determining recovered CO_2)	If data are not available, zero CO_2 recovery is assumed	UP: Urea production	• National statistics	• Confirm totals align with official industry statistics. • Reconcile units.
3	Determine EFs for ammonia production	EF = FR × CCF × COF × 44/12	CCF = 15.3 kg/GJ (or 21.0 kg/GJ for partial oxidation) COF = 1 FR: fuel requirement [GJ(NCV)/tonne NH_3]	• IPCC default values	
4	Apply default EFs	CO_2 _production = AP × EF			
6	Calculate recovered CO_2	R_CO_2 = UP x 44/60			
7	Calculate total CO_2 Emission	Total CO_2 = CO_2 _production – R_CO_2			
9	Report and document	Provide assumptions, EFs, and data sources used			Report the total ammonia production by process, corresponding EFs used und amount of recovered CO_2

TIER 2

This approach requires plant-level data on ammonia production classified by fuel type and production process. These are then used to determine the total requirement for fuel as feedstock. Other required data such as fuel consumption and EFs per process type, CCF or COF can be derived using either default data from the 2006 IPCC Guidelines or the country specific data from the energy sector. In case CO_2 is recovered (urea production) or captured and stored (CCS), the quantities need to be provided at the plant level as well.

Table 18: Calculation of CO_2 emissions from ammonia production using Tier 2 method

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
1	Compile ammonia production per fuel and production type	If production data are not available, production capacity can be used	AP_ij: ammonia production per fuel type i and process type j	• Plant data	• Confirm totals align with official industry statistics. • Reconcile units.
2	Compile fuel requirement per fuel and production type	If production data are not available, production capacity can be used	FR_ij: = total fuel requirement per unit of output for fuel type i and process type j	• IPCC default values	• Confirm totals align with official industry statistics. • Reconcile units.
3	Compile recovered CO_2	• CO_2 recovered for downstream use (urea production, CO_2 capture and storage (CCS)) • If data are not available, zero CO_2 recovery is assumed	R_CO_2: recovered CO_2	• Plant data	• Confirm totals align with official industry statistics. • Reconcile units.
4	Determine total fuel requirement per fuel type	$TFR\_{}_i = \sum j(AP\_{}_{ij} \times FR\_{}_{ij})$	TFR_*ij*: = total fuel requirement per unit of output for fuel type *i*		
5	Apply EFs per fuel type	CO_2 _production = $\sum i(TFR\_i \times CC_i \times COF_i \times {}^{44}/_{12})$	CCF_i = 15.3 kg/GJ (or 21.0 kg/GJ for partial oxidation) COF_i = 1	Parameters: • Plant data • IPCC default values	• check if estimated EF are within range of default EF
6	Calculate total CO_2 Emission	Total CO_2 = CO_2 _production – R_CO_2			
7	Report and document	Provide assumptions, EFs, and data sources used			Report the total ammonia production by process and fuel type, corresponding EFs used und amount of recovered CO_2

Box 17.

Türkiye calculates the CO_2 emissions from ammonia production using a Tier 2 methodology. This approach involves multiplying total fuel requirement by the country-specific carbon content and the carbon oxidation factor. Ammonia production and fuel requirement data are obtained from producers on the annual basis. Ammonia production and natural gas consumption data are measured by on-line flow meters in the process from the producers. Urea production data is calculated from the raw material consumption. Since there are only three production plants in Türkiye, the activity data are confidential.

TIER 3

This method requires detailed plant-level data on fuel consumption for the ammonia production. These are summed to obtain the total process fuel consumption per fuel type. In case CO_2 is recovered (urea production) or captured and stored (CCS), these amounts are needed at the plant level. If the fuel use per unit of ammonia is used for the calculations, the plant-level production data must also be collected. Otherwise, the plant-level data on ammonia production are only needed for reporting purposes.

It is a good practice to obtain values for CCF and COF from producers or to use the country-specific energy sector information.

Table 19: How to calculate CO2 emissions from ammonia production using Tier 3 method

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
1	Compile ammonia production	Only for reporting purposes		• Plant data	• Confirm totals align with official industry statistics. • Reconcile units.
2	Compile total fuel requirement per plant	TFR_i=∑*n* TFR_$_{in}$	TFR$_{in}$: = total fuel requirement for fuel type i and plant *n*	• Plant data	• Confirm totals align with official industry statistics. • Reconcile units.
3	Compile recovered CO_2	• CO_2 recovered for downstream use (urea production, CO_2 capture and storage (CCS)) • If data are not available, zero CO_2 recovery is assumed	R_CO_2: recovered CO_2	• Plant data	• Confirm totals align with official industry statistics. • Reconcile units.
5	Apply EFs per fuel type	CO_2 _production = ∑i(TFR_$_i$ × CC_$_i$× COF_$_i$ × 44/12)	CCF_i = 15.3 kg/GJ (or 21.0 kg/GJ for partial oxidation) COF_i = 1		
6	Calculate total CO_2 Emission	Total CO_2 = CO_2 _production – R_CO_2	CCF_i = 15.3 kg/GJ (or 21.0 kg/GJ for partial oxidation) COF_i = 1	Parameters: • Plant data • IPCC default values	• check if estimated EF are within range of default EF

Step	What to do	How to calculate	Parameters	Possible sources	QA/QC checks
7	Report and document	Provide assumptions, EFs, and data sources used			Report the total fuel consumption per fuel type,corresponding EFs used und amount of recovered CO_2. Also report ammonia production.

Box 18.

Brazil estimates CO_2 emissions from ammonia production based on the measurement of fuels consumed as feedstock in the process at the plant level (Tier 3). However, for confidentiality reasons, the two operating plants did not disclose the fuel consumption. Instead, the country provided average EFs for three existing production routes in Brazil:

- Asphalt waste: 2.0 t of CO_2/t of ammonia
- Refinery gas: 1.3 t of CO_2/t of ammonia
- Natural gas: 1.2 t of CO_2/t of ammonia

From these values and the feedstocks used in Brazil, an average EF of 1.46 t of CO_2 per tonne of ammonia was determined as national EF.

The amount of the CO_2 recovered for urea production is also accounted for and subtracted. This prevents an overestimation of emissions. This approach ensures that the emissions reflect the specific conditions of the Brazilian industry rather than relying on global averages.

3.3.2 Nitric acid production

Nitric acid (HNO_3) is primarily used as a raw material in the production of nitrogenous fertilisers. It also finds applications in the manufacture of adipic acid, explosives such as dynamite, metal etching, and ferrous metal processing. The main GHG produced during the production process is nitrous oxide (N_2O). It is a by-product of the high-temperature oxidation of NH_3. If not properly abated, nitric acid production can be a significant source of atmospheric N_2O emissions.

It is not possible to establish a direct relationship between the N_2O emissions and the NH_3 input. The amount of generated NO_2 depends on the production parameters such as combustion conditions and catalyst composition. Additionally, the amount of NO_2 is affected by abatement[32] processes. These may be intentional measures to reduce emissions or non-intentional measures originally designed for other purposes.

As with ammonia, completeness can be improved by ensuring that emissions of any fugitive CH_4 are included. These may come from either the primary reformer stage or catalytic methanation of the CO_2 process. The 2006 IPCC Guidelines (Volume 1, Chapter 7: General Guidance and Reporting) show how to include emissions of nitrogen oxides (NOx), carbon monoxide (CO) and sulphur dioxide (SO_2) from the primary reformer stage.

32 Reduction or removal of chemical substances from emissions or effluents by applying chemical reactions or processes.

Choice of method

Table 20: Overview methodological Tiers in nitric acid production

Tier	What to calculate	Key inputs	Typical data sources
Tier 1	Estimate N_2O emissions from HNO_3 production using default EFs	• National HNO_3 production • Default EF	• National industry statistics • Plant reports • Trade and industry association data
Tier 2	Use plant level production data disaggregated by technology type with country specific or default EFs	• HNO_3 – Production by type • EFs classified by technology type (including abatement)	• Plant-level measurements • National surveys • Industry association data (plant level data)
Tier 3	Use plant level data from direct measurements	• HNO_3 – Production by plant • derive EFs from direct plant-level measurements • N_2O Abatement by plant	• Periodic or continuous emission monitoring (though continuous monitoring remains relatively rare due to costs) • sampling approaches

TIER 1
It is good practice to assume no abatement of N_2O and to use the highest EF based on the technology type. If national production data not available, capacity data can be used. Then it is a good practice to multiply capacity by 80% utilisation factor (±10%, i.e., 70-90%)

TIER 2
It is a good practice to use default factors only if plant-level data for EF are not available. For activity data, it is a good practice to gather production, generation and abatement data at consistent levels.

TIER 3
Good practice involves conducting sampling and analysis whenever a plant undergoes significant process changes. It is also advisable to contact plants annually to monitor specific destruction technologies.

When measuring emission rates and abatement, it is good practice to obtain precise measurements of both the emissions from the exit stream and the uncontrolled stream. If data are only available for the exit stream, these should be used for calculations, while any abatement should be neglected in the emission calculations but listed separately for reporting purposes.

For activity data, a good practice is to gather production, generation, and destruction data at consistent levels of detail. For example, when plant-level EFs are used, it is recommended to collect plant-level production data to ensure accuracy and consistency.

Box 19. IPCC Refinement 2019 – Nitric Acid Production, Choice of EFs

The 2019 Refinement contains a refinement for the determination of EFs for the Tier 2 level:

- A new table was introduced to distinguish five production process types according to the pressures applied in the oxidation and absorption stage as presented.
- Default EFs have been updated.

Box 20.

Brazil estimates N_2O emissions from nitric acid production on two different levels:

- Tier 3 approach is employed for plants carrying out Clean Development Mechanism (CDM) projects. In those cases, data from direct measurements were used to determine specific EFs for each plant.
- Tier 1 approach was used for the remaining plants by applying the 2006 IPCC Guidelines default EFs.

Data on the total HNO_3 production were obtained from the Brazilian Chemical Industry Association (Abiquim).

NOx emissions were accounted for using a uniform emission factor of 1.75 kg NOx per tonne of HNO_3, which is below the default value from the 2006 IPCC Guidelines. This deviation is justified by the assertion that Brazil has measures in place to control emissions of these gases.

3.3.3 Petrochemical and carbon black production

The petrochemical industry primarily utilises fossil fuels such as natural gas or petroleum refinery products such as naphtha, as its fundamental feedstocks. These are used to produce a wide range of chemicals such as methanol, ethylene and its derivatives, propylene or acrylonitrile.

Although carbon black[33] is not classified as a petrochemical, its production process is intrinsically linked to this sector, as it also relies on petrochemical feedstocks. Within both the petrochemical and carbon black industries, primary fossil fuels are employed for non-fuel purposes in the manufacturing of these products. This may involve the combustion of a portion of the hydrocarbon content to generate heat and produce secondary fuels, such as off-gases.

According to the 2006 IPCC Guidelines, combustion emissions derived from fuels obtained from the feedstock should be attributed to the relevant source category within the IPPU sector. However, if these fuels are not consumed within the source category but are instead transferred for combustion elsewhere, their emissions should be reported under the appropriate Energy sector category. It is crucial to ascertain whether fuels used in petrochemical industries are already accounted for in national energy statistics. If this is the case, the resulting emissions must be deducted from the calculated energy sector emissions to prevent double counting.

The primary GHG emitted during the production of petrochemicals and carbon black are CO_2 and CH_4. The latter may be fugitive emissions and/or process vent emissions. These include incomplete combustion of waste gas in flare and energy recovery systems.

Choice of method

The emissions generated during production processes are highly dependent on both the specific process and the feedstock employed. Consequently, the chosen methodology for emission estimation should be reiterated for each distinct product, process, and feedstock. The selection of an appropriate Tier depends upon national circumstances. This can be determined by following the decision trees outlined in Figure 3.8 (CO_2 emissions) and Figure 3.9 (CH_4 emissions) of the 2006 IPCC Guidelines (Volume 3, Chapter 3).

33 Fine, powdered form of nearly pure elemental carbon produced by the incomplete combustion or thermal decomposition of hydrocarbons.

Table 21: Overview methodological Tiers in petrochemical and carbon black production

Tier	What to calculate	Key inputs	Typical data sources
Tier 1	Estimate CO_2 and CH_4 emissions from national production data using default EFs	• National production data per product (can be also estimated from feedstock consumption) • Default EF per product	• National industry statistics • Plant reports • Trade and industry association data
Tier 2	Estimate CO_2 emissions from the difference between total carbon input and amount of carbon exiting as petrochemical products	• Feedstock consumption and production data • Fata on disposition of primary and secondary products	• Plant-level measurements • National surveys • Industry association data (plant level data)
Tier 3	Estimate CO_2 and CH_4 emissions from plant-level measurements	E_CO_2: • Plant-level data for fuel consumption per product (combustion, flaring) • Calculate EF_CO_2 from the carbon content of the fuel and the combustion oxidation factor (or use default values). E_CH_4: • Atmospheric concentrations of Volatile Organic Compounds (VOCs) to estimate fugitive CH_4 emissions	• Periodic or continuous measurements or sampling approaches • VOC: i) measurements directly above the plants or within the plume (preferred), or ii) measurements from plant exhaust gas streams and from plant valves, fittings, and related equipment

Box 21.

Germany estimates the CO_2 emissions from petrochemicals using a Tier 2 methodology. This is a mass balance approach. As this method is not suitable for the methane (CH_4) estimation, a Tier 1 approach is used. Nationally aggregated production quantities are used, since plant-level activity data are not available. All activity data are sourced from the German Federal Statistical Office.

The country-specific EFs used are those reported under the EU ETS. These are lower than the default values from the 2006 IPCC Guidelines. This approach is justified to prevent double counting, as most combustion-related emissions are already accounted for in the energy sector within Germany's GHG inventory.

4 Practical approaches to data collection in industry

This section provides practical recommendations to identify industrial emitters, gather consistent activity data, and work efficiently with regulators, industry associations, and facilities. The aim is to make data collection efficient, accurate, and replicable, while minimising the burden on industry by reusing existing data systems.

The first step in **identifying industrial emitters** is to find the relevant sources of information, such as environmental permitting and compliance registries (air, water or waste), energy regulator lists (power/heat producers), and industry association rosters. Building a master facility list with the fields necessary for allocation and confidentiality can help map the sectors and data sources. The data collected can include facility name, ISIC codes, IPCC category/subcategory, region, permit IDs, contacts, and an auto producer flag.

One practical way to reduce the burden of **data collection** is to reuse existing reporting channels. Many of the data points required for the national GHG inventories can be added to existing environmental or sectoral reporting forms, rather than creating a new process. **Examples of such existing reporting systems include:**

- Environmental permit compliance reports submitted to environmental agencies,
- Energy statistics collected by national statistical offices or energy ministries,
- Pollutant release and transfer registers that already capture facility-level emissions data,
- Air quality monitoring and reporting systems,
- Annual industrial production surveys conducted by statistical agencies,
- Sector-specific reporting to industry regulators (e.g., mining, petrochemical or manufacturing oversight bodies); and mandatory corporate sustainability or environmental reports required under national legislation.

For combustion processes, the standardised data fields can include fuel type and quantity (with units), net calorific values or energy content, and basic technology descriptions. For cement production, fields for clinker production, CKD/bypass dust practices and clinker trade are essential. Simple unit and range checks embedded in the forms prevent common errors at source. Providing templates and schedules helps ensure a sustainable data flow.

Industry associations can be powerful **intermediaries**. Where regular industry reporting already exists, associations can integrate a small number of GHG inventory fields, coordinate timelines and carry out initial validation, resulting in more comprehensive submissions. They can also address confidentiality issues by collecting facility-level data and transmitting only aggregated values to the national GHG inventory team. The team can maintain secure archives for QA/QC and time-series recalculation. In practice, the involvement of industry associations is typically established through formal mechanisms tailored to national legal and institutional contexts. Some countries use legally binding agreements or contracts between government agencies and industry associations. In Germany, the Federal Ministry of Economics and the Environment Agency concluded formal data provision agreements with industry associations for specific emission categories.

Other approaches include voluntary partnerships formalised through memoranda of understanding, regulatory requirements that designate industry associations as data collection entities, or contracted arrangements where associations are compensated for their data collection and validation services. The chosen mechanism depends on existing legal frameworks, industry structure, and resource availability. This arrangement should be formalised and referenced in the inventory's QA/QC plan, detailing who collects what, how it is validated, how it is aggregated and how confidentiality is safeguarded.

Box 22. Engagement with non-governmental organizations

Germany established a systematic approach to engage non-governmental organizations in GHG inventory preparation through binding data provision agreements. In 2008, a sample agreement framework was developed that can be adapted to individual data suppliers' needs. Since 2009, the Federal Ministry of Economics and Technology (BMWi) and the German Environment Agency (UBA) have concluded agreements with various industry partners, including the German Chemical Industry Association (VCI) and producers for ammonia and nitric acid emissions, adipic acid producers, the VDD industry association for bitumen products, and all three soda ash production facilities in Germany. These agreements are regularly updated to align with evolving reporting requirements, such as the 2014 revision to meet UNFCCC Guidelines and the 2006 IPCC Guidelines. Under this system, companies report production data annually, which UBA aggregates and uses in time-series formats, ensuring consistent, high-quality data directly from industry sources while maintaining commercial confidentiality.

Facility-level reporting can be supported through formal memoranda of understandings (MoUs) with the facilities. The nature of these MoUs—whether voluntary or mandatory—depends on national legislation and reporting requirements. In some countries, facilities above certain thresholds are legally required to report emissions data under environmental regulations (e.g. Brazil) or climate legislation, so the MoU just formalises a mandatory process. In other contexts, MoUs may be voluntary, requiring incentives to encourage participation.

Incentives for facility participation can include recognition in national sustainability reports, preferential access to government programs or green financing, early engagement in policy development affecting their sector, technical support for emissions monitoring and reduction, or compliance credit where reporting contributes to meeting other regulatory obligations. Conversely, non-participation may result in the use of conservative default EFs or regulatory penalties where reporting is mandated.

If facilities hesitate to participate due to confidentiality concerns, emphasising data aggregation procedures and the use of notation keys in public reports can help build trust. Where only a few facilities operate in a category, it is advisable to publish only aggregated data, for example by combining subsectors or regions, or by using the data for GHG emission estimations (e.g. by using the notation key C for "Confidential"). These MoUs should specify the scope (i.e. which facilities, fuels and processes are covered), the required data and units, the aggregation level, reporting frequency and timelines, and the QA/QC expectations.

Industry stakeholders may not be aware of the requirements for GHG inventories, including the specific information required by the national GHG inventory team. To effectively engage the industry, national GHG inventory teams should clearly articulate the benefits and rationale for participation. Key arguments can be:

- Accurate facility-specific data prevents the use of conservative default EFs that may overestimate emissions and misrepresent the industry performance.
- Direct industry engagement ensures that national policies and reduction targets are based on realistic baselines rather than potentially inaccurate estimates.
- Participation demonstrates corporate environmental responsibility and can provide reputational benefits with investors, customers and regulators.
- Quality data from the industry actors can reduce the need for regulatory monitoring or mandatory reporting schemes in the future.

Short training sessions or **guidance materials** can help generate a common understanding of why specific data is required and how it might differ from the data already reported under other legal requirements (e.g. air quality reporting). These sessions should explain how the industry contributions improve national data quality and policy making (rather than framing data provision as a burden) and how confidential data is protected.

Box 23. Data collection

Securing robust, confidential activity data from industry requires formal mechanisms. Legal mandates, such as **reporting thresholds** (e.g., ≥10,000 t CO_2-eq in **Brazil**), create clear obligations and allow enforcement.

Kazakhstan uses **non-disclosure agreements** (NDAs). The inventory contractor (Zhasyl Damu JSC) signs NDAs with major emitters to protect plant-level production and fuel data. Facility-level inputs are **aggregated to regional totals** before public release, applying **IPCC notation keys** (included elsewhere, IE) where needed to mask individual plants. When direct data are missing, compilers may apply fuel sales or national statistics as proxies, clearly flagging the Tier downgrade and associated uncertainty. Encrypted uploads to a national inventory portal, avoiding e-mail exchanges and tracking data provenance are some of the secure transmission methods that Kazakhstan implements to have controlled access to the National Inventory System.

With fewer than three installations, the **notation key** C (for "Confidential") could be used instead of the actual values. **Türkiye** reported the EFs used for aluminium production as confidential as there is only one producer in the country.

Argentina develops country-specific natural gas EFs under confidentiality agreements with gas suppliers. These factors are compared with IPCC defaults, reducing uncertainty from ±10% to ±5% for key combustion categories.

Most cement plants in **Türkiye** are members of the Turkish Cement Manufacturers Association (TurkCimento) and report their activity data to the association on a monthly basis. TurkCimento publishes this data as industry-specific statistics on its website. The activity data of plants that are not members of TurkCimento are collected via a survey. This data is also verified due to the requirements of the Turkish Regulation on the Monitoring of Greenhouse Gas Emissions.

5 Outlook and conclusion

This guide explains the IPCC methods and real-world practices to help governments produce coherent, high-quality inventories of industry-related GHG emissions across the Energy and IPPU sectors, reduce uncertainty, and support evidence-based policy design. When compilers clarify sector boundaries (combustion vs. process), prioritise key categories, and embed QA/QC and documentation processes, GHG emission inventories become transparent, consistent, and reproducible over time.

Near term priorities for national GHG inventory teams include:

- Institutionalising roles, data flows, and cooperation with industry to improve coverage, while documenting methods, assumptions, and sources for efficient updates, and managing confidentiality.
- Identifying key categories and moving from Tier 1 (defaults) towards higher Tiers (country or facility-specific data), while maintaining consistent time series and recalculating as methods improve.
- Leveraging facility level data (e.g., technology specific activity data) and anticipating interoperability with product level regimes (e.g., CBAM) to minimise reporting burden and avoid double counting.
- Incorporating relevant updates from the 2019 Refinement, whenever feasible, to reflect advances in methods and parameters.

Looking ahead, stronger national systems, better plant-level data, and progressive Tier upgrades will deliver more accurate inventories. Paired with the ETF's regular reporting cycle and collaborative platforms like the Climate Club, these improvements will help countries track industrial emissions credibly, target mitigation in "hard-to-abate" subsectors and mobilise support for Article 6 implementation consistent with long-term climate goals, while solidifying their position on international markets for the future.

6 Bibliography

AGC Glass Europe. (n.d.).
Carbon footprint. Retrieved January 16, 2026, from
https://www.agc-glass.eu/en/sustainability/decarbonisation/carbon-footprint

Australian Government Department of Climate Change, Energy, the Environment and Water. (2025).
Australia's carbon leakage review.
https://www.dcceew.gov.au/climate-change/emissions-reduction/review-carbon-leakage

C40 Cities. (2016).
Press release: The Global Covenant of Mayors for Climate & Energy announces its global impact.
https://www.c40.org/news/press-release-the-global-covenant-of-mayors-for-climate-energy-announces-its-glob-al-impact/

Climate Club. (n.d.).
The Climate Club: Industry decarbonisation. Retrieved April 14, 2026, from
https://climate-club.org/

Climate Watch. (n.d.).
Global historical emissions. Retrieved January 16, 2026, from
https://www.climatewatchdata.org/embed/ghg-emissions?ap3c=IGZq2P1FS0xArgwAAGZq2P2hk-Udzu0soaG9k-ax76h6X5pW5cg&breakBy=sector&chartType=line&end_year=2022&sectors=manufacturing-construction&source=-Climate%20Watch&start_year=1990

European Bureau for Research on Industrial Transformation and Emissions. (n.d.).
Iron and steel production. Retrieved January 8, 2026, from
https://bureau-industrial-transformation.jrc.ec.europa.eu/reference/iron-and-steel-production

European Commission. (n.d.).
Carbon border adjustment mechanism: The EU's environmental policy tool for fair carbon emissions pricing. Retrieved November 5, 2025, from
https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en

GOV.UK. (2025, April 24).
Draft legislation: Carbon border adjustment mechanism.
https://www.gov.uk/government/consultations/draft-legislation-carbon-border-adjustment-mechanism

Government of Sierra Leone. (2021).
Sierra Leone's first biennial update report: Government of Sierra Leone's submission to UNFCCC.
https://unfccc.int/sites/default/files/resource/Sierra%20Leone%20First%20BUR%20_Final.pdf

Hannant, D. J. (2000).
Cement-based composites.

Harries, J., Moosmann, L., Urrutia, C., Essus, C., Gomez-Villota, F., & Zarzo Fuertes, O. (2023).
Climate action and transparency under the Paris Agreement. Partnership on Transparency in the Paris Agreement.
https://transparency-partnership.net/system/files/document/Accessible%20Version%20-%20GIZ_Climate%20Action_EN%20BF%20230616_0.pdf

Hasanbeigi, A. (2022).
Steel climate impact: An international benchmarking of energy and CO_2 intensities. Global Efficiency Intelligence.
https://static1.squarespace.com/static/5877e86f9de4bb8bce72105c/t/624ebc5e1f5e2f3078c53a07/1649327229553/Steel+climate+impact-benchmarking+report+7April2022.pdf

Hezir, J. S., Moniz, E. J., Kizer, A., Jeong, M., Savitz, S. F., & Smith, S. F. (2025).
EFI Foundation carbon accounting framework for a comprehensive new product and entity-level ledger-based carbon accounting system. EFI Foundation.
https://efifoundation.org/wp-content/uploads/sites/3/2025/06/EFI-Foundation-Carbon-Accounting-Framework-for-a-Comprehensive-New-Product-and-Entity-Level-Ledger-Based-Carbon-Accounting-System.pdf

ICAP. (n.d.).
Welcome to the ICAP ETS map. Retrieved January 8, 2026, from
https://icapcarbonaction.com/en/ets

IEA. (2021).
Ammonia Technology Roadmap. IEA.

IEA. (2023a).
Cement. IEA.
https://www.iea.org/energy-system/industry/cement

IEA. (2023b).
Chemicals - IEA.
https://www.iea.org/energy-system/industry/chemicals

IPCC. (2006a).
2006 IPCC guidelines for national greenhouse gas inventories. IPCC.
https://www.ipcc-nggip.iges.or.jp/public/2006gl/

IPCC. (2006b).
Chapter 1: Introduction to the 2006 guidelines. In 2006 IPCC guidelines for national greenhouse gas inventories (Vol. 1). IPCC.
https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_1_Ch1_Introduction.pdf

IPCC. (2006c).
Chapter 2: Mineral industry emissions. In 2006 IPCC guidelines for national greenhouse gas inventories (Vol. 3). IPCC.
https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_2_Ch2_Mineral_Industry.pdf

IPCC (2006d).
Volume 3: Industrial Processes and Product Use: Chapter 2: Mineral Industry Emissions. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_2_Ch2_Mineral_Industry.pdf

IPCC. (2019).
2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories. IPCC.
https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

Lempriere, M. (2023).
Steel industry makes "pivotal" shift towards lower-carbon production. Carbon Brief.
https://www.carbonbrief.org/steel-industry-makes-pivotal-shift-towards-lower-carbon-production/

Lins, C., Mascotte, B., & Dain, T. (2025).
Leveraging carbon accounting and product GHG intensity standards in the context of COP30: Contributions to the Brazilian COP30 Presidency[Strategic insights report]. Catavento; Brazilian Center for International Relations.
https://catavento.biz/wp-content/uploads/2025/08/2025_Catavento_CEBRI_Carbon-accounting-roundtable_Strategic-Insights-Report_v18.08.2025.pdf

Partnership on Transparency in the Paris Agreement. (2022).
Updated: Good practice study on GHG inventories for the waste sector. Partnership on Transparency in the Paris Agreement.
https://transparency-partnership.net/publications-tools/updated-good-practice-study-ghg-inventories-waste-sector

Ritchie, H., Rosado, P., & Roser, M. (2020).
Breakdown of carbon dioxide, methane, and nitrous oxide emissions by sector. Our World in Data.
https://ourworldindata.org/emissions-by-sector

TT:CLEAR. (n.d.).
Transformative industry. Retrieved January 8, 2026, from
https://unfccc.int/ttclear/tec/transformativeindustry.html

UNFCCC. (2015).
Paris Agreement. UNFCCC.
https://unfccc.int/sites/default/files/english_paris_agreement.pdf

UNFCCC. (2018).
Decision 18/CMA.1: Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement. UNFCCC.
https://unfccc.int/resource/tet/0/00mpg.pdf

UNIDO. (n.d.).
Decoding industrial decarbonization: Iron and steel — What is the state of decarbonization technologies? UNIDO. Retrieved April 14, 2026, from
https://decarbonization.unido.org/wp-content/uploads/2025/10/brief-nzp_a4_9-oct.pdf

World Economic Forum. (2024a).
Cement industry net-zero tracker: The industry must prioritise supplementary cementitious materials, efficiency strategies and bioenergy now, while advancing CCUS, electrification and fuel shifts for long-term reductions. World Economic Forum.
https://reports.weforum.org/docs/WEF_Net_Zero_Industry_Tracker_2024_Cement.pdf

World Economic Forum. (2024b).
Net-zero industry tracker 2024 edition: Insight report. World Economic Forum.
https://reports.weforum.org/docs/WEF_Net_Zero_Industry_Tracker_2024.pdf

World Resources Institute. (2025, November 5).
Where do emissions come from? 4 charts explain greenhouse gas emissions by sector. World Resources Institute.
https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors

Worldsteel Association. (2025).
2025 world steel in figures. Worldsteel Association.
https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2025-2.pdf

Annex I Countries in the study

Country	Sources
Argentina	2024 Biennial Transparency Report https://unfccc.int/sites/default/files/resource/IBT1%20Argentina_2024.pdf 2024 National Inventory Report https://unfccc.int/sites/default/files/resource/INI%20del%20IBT1_2024.pdf
Chile	Chile Biennial Update Report 2023 https://unfccc.int/documents/627375
Brazil	First Biennial Transparency Report of Brazil https://unfccc.int/sites/default/files/resource/BRA_BTR1_2024_ENG.pdf Fifth Biennial Update Report of Brazil unfccc.int/sites/default/files/resource/BRA_BUR5_EN.pdf Brazil's National Inventory Report of Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases 2024 https://unfccc.int/sites/default/files/resource/BRA_NIR_2024_ENG.pdf
Germany	2024 National Inventory Report https://unfccc.int/sites/default/files/resource/2024-04-15_DE_NID_2024_UNFCCC_english.pdf
Kazakhstan	2023 National Inventory Report https://unfccc.int/sites/default/files/resource/NID%20RK%202025.pdf
Türkiye	2023 National Inventory Report https://unfccc.int/documents/627786
Uzbekistan	2024 Biennial Transparency Report https://unfccc.int/sites/default/files/resource/BTR1_Uzbekistan_eng.pdf 2024 National Inventory Report https://unfccc.int/sites/default/files/resource/NIR_BTR_kadastrGHG_Uzbekistan_0.pdf

Annex II Useful data and information sources

IPCC GUIDELINES

- 2000 IPCC Good Practice Guidance:
  https://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html
- 2006 IPCC Guidelines:
  https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
- 2006 IPCC Guidelines Worksheets:
  https://www.ipcc-nggip.iges.or.jp/public/2006gl/worksheets/2006GL_Worksheets.zip
- 2019 IPCC Refinement:
  https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

UNFCCC DOCUMENTS

- Biennial Transparency Reports and National Inventory Documents:
  https://unfccc.int/reports
- Information on reporting and review under the Paris Agreement:
  https://unfccc.int/reporting-and-review

DATABASES

- IPCC EF Database (EFDB):
  https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
- The US Geological Survey:
  International Minerals Statistics and Information | U.S. Geological Survey
- World Steel Association:
  https://worldsteel.org/data/
- International Aluminium Institute:
  Primary Aluminium Production – International Aluminium Institute
- Ozone Secretariat:
  https://ozone.unep.org/countries/data-table?q=countries/data

INSTITUTIONS AND PROGRAMMES THAT PROVIDE SUPPORT FOR CAPACITY DEVELOPMENT FOR ACCOUNTING OF GREENHOUSE GASES AND MITIGATION ACTIONS

- UNFCCC CGE Training Materials for the Preparation of National Communications from Non-Annex I Parties:
  https://unfccc.int/process-and-meetings/bodies/constituted-bodies/consultative-group-of-experts/cge-training-materials/cge-training-materials-for-the-preparation-of-national-communications

- UNFCCC Reference Manual for the ETF under the Paris Agreement:
  https://unfccc.int/resource/tet/0/01refman.pdf

- UNFCCC CGE Technical handbook for developing country Parties on preparing for implementation of the ETF under the Paris Agreement:
  https://unfccc.int/process-and-meetings/transparency-and-reporting/support-for-developing-countries/consultative-group-of-experts/enhanced-transparency-framework-technical-material#eq-1

- UNFCCC BTR Review Training (IPPU):
  https://unfccc.int/sites/default/files/resource/230403%20IPPU%20final_formatted_19.09.2023.pdf

- UNFCCC BTR Review Training (Energy):
  https://unfccc.int/sites/default/files/resource/CourseB2_Energy_Ed1.pdf

- UNFCCC CGE Toolbox on institutional arrangements:
  https://unfccc.int/CGE/IA

- Partnership on Transparency in the Paris Agreement (PATPA):
  https://transparency-partnership.net/

- Climate Transparency Platform:
  https://climate-transparency-platform.org/

- Initiative for Climate Action Transparency (ICAT):
  https://climateactiontransparency.org/

- NDC Partnership Climate Toolbox:
  https://ndcpartnership.org/knowledge-portal/climate-toolbox

- UNIDO Net Zero Partnership for Industrial Decarbonization:
  https://decarbonization.unido.org/projects/net-zero-partnership/

- United States Environmental Protection Agency (EPA) Toolkit for Building National GHG Inventory Systems:
  https://19january2021snapshot.epa.gov/ghgemissions/toolkit-building-national-ghg-inventory-systems_.html

- EPA Sector Lead Roles and Responsibilities Guide for IPPU:
  https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.epa.gov%2Fsites%2Fdefault%2Ffiles%2F2020-11%2Fsector_roles_and_responsibilities_-_ippu.docx&wdOrigin=BROWSELINK

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